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Publication date:
1997

Document Version
Publisher's PDF, also known as Version of record

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Citation (APA):
Madsen, P. H., Andersen, P. D. (Ed.), & Skrumsager, B. (1997). *Meteorology and Wind Energy Department annual report 1996*. Denmark. Forskningscenter Risoe. Risoe-R No. 948(EN)

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Meteorology and Wind Energy Department Annual Report 1996

P. Hauge Madsen, P. Dannemand Andersen and
B. Skrumsager (eds)

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Risø National Laboratory, Roskilde, Denmark
July 1997

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Risø National Laboratory, Roskilde, Denmark
July 1997

Abstract

In 1996 the Meteorology and Wind Energy Department has performed research within the programme areas: (1) wind energy and (2) atmospheric processes. The objectives are through research into boundary layer meteorology, fluid dynamics, aerodynamics and structural mechanics to contribute with new knowledge within (1) wind energy in relation to development, manufacturing, operation and export as well as testing and certification of wind turbines, and (2) aspects of boundary-layer meteorology related to environmental and energy problems of society. The work is supported by the research programs of eg the Ministry of Environment and Energy, by the Danish Research Councils, some international research councils, EU as well as by industry.

Through our research and development work we develop and provide methodologies including computer models for use by industry, institutions, and governmental authorities. In the long view we are developing facilities and programs enabling us to serve as a national and European centre for wind-energy and boundary-layer meteorological research.

A summary of our activities in 1996 is presented.

Cover photo: The Wind Energy Centre at Risø by Nielsen, Nielsen and Nielsen, Architects, Århus, Denmark.

ISBN 87-550-2251-0
ISSN 0106-2840
ISSN 0903-9627

Information Service Department · Risø · 1997

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1 Introduction

In 1996 the Meteorology and Wind Energy Department employed a staff of 87 persons including researchers, technicians, PhD's, postdoctorates and administrative staff. Through 1996 our department was organized in the research programmes "Transport and Exchange of Atmospheric Pollution" (TUF), "Wind Resources and Wind Loads" (VIR), "Wind Energy Systems" (VIS), "Wind Turbines" (VIM) and in the two special tasks "Type Approval" and "Test and Measurement", both in relation to wind turbines.

The primary objectives of the Meteorology and Wind Energy Department are through research into boundary layer meteorology, fluid dynamics, aerodynamics and structural mechanics to contribute with new knowledge within (1) wind energy in relation to development, manufacturing, operation and export as well as testing and certification of wind turbines, and (2) aspects of boundary-layer meteorology related to environmental and energy problems of society.

There is an increasing demand for a better understanding of and ability to describe and estimate flows and fluxes in the lower atmosphere with application to wind-power technology, environmental science and technology, and general wind engineering. Through research and development within these fields, the aim of the department is to be able to procure knowledge, methods, and solution models for industry, institutions, and governmental authorities. A long-term goal of the department is to continue the development of facilities and programs to serve as a national and European centre for wind-energy and boundary-layer meteorological research.

In 1996 the Meteorology and Wind Energy Department has performed research within the programme areas: (1) wind energy and (2) atmospheric processes.

Wind energy

To meet the objectives the wind energy activities are divided into the following categories:

Strategic and applied research within the research themes of wind resources and wind loads, aerodynamics, wind-power technology including electrical grids with a high wind penetration, and tests and measurements. The research comprises basic research and genetic technology development/innovation as well as applied research, and its aim is to acquire and systematize knowledge relevant to wind energy and wind-turbine technology and develop the theoretical tools necessary to improve insight and understanding within these areas.

Certification of wind turbines with the purpose of ensuring their safety and documentation of quality. The certification of wind turbines and wind turbine projects are carried out on commercial terms.

Testing of wind turbines and of major components (eg wind-turbine blades) for certification purposes. Measurements of wind loads and wind turbine response and behaviour at the Test Station or in the field are made both for research and development purposes as well as certification purposes.

Dissemination of information to industry, international co-operation on standardization, test, and certification procedures, and consulting assistance to authorities, government agencies, electrical utilities, and other planners and users of wind power.

High-penetration systems: formulation and development of a general technical approach to the inclusion of a large fraction of wind power in power supply systems.

For more than 10 years the department has co-ordinated the EU programme on mapping the wind resources of the EU countries. The effort led to the publication of the European Wind Atlas in 1989 and to the issuing of the PC program Wind Atlas Analysis and Application Program (WA^{S}P), which is in world-wide use.

Atmospheric processes

The department's activities within environmental science are largely centred on research into transport and fluxes of atmospheric trace constituents in the atmosphere including studies of chemical and physical transformations.

We are actively engaged in the activities of the Danish Centre for Atmospheric Research (DCAR) especially in co-operation with the Danish National Environmental Research Institute (NERI). One of the joint projects is RIMI, whose objective is the study of the transport and transformation of nitrogen compounds close to the surface. Also joint research is carried out through the centres under the Danish Environmental Research Programme (SMP).

Exchange of energy and various compounds between the atmosphere and inhomogeneous terrestrial surfaces is an important research field in the department, and fluxes over forests and sea are modeled and measured.

The main work on atmospheric dispersion has been the development of online models and experiments aimed at improved emergency preparedness both for conventional and nuclear releases. Models for atmospheric dispersion developed in the department have been integrated into European and Danish decision support systems.

Structure of the report

This annual report presents the programmes and other tasks in the department including research highlights and other achievements of 1996. The topics "atmospheric fluxes over biosystems" and "wind turbine blade design" receive special attention and the report concludes with dissemination and utilization of the research results, staff and publications in 1996.

Worldwide web

Since August 1995 the Meteorology and Wind Energy Department has been present on Worldwide Web (WWW). The web pages present the department, its programmes, research, staff and special projects, facilities or products. The pages are constantly updated. The present annual report can be found in the department's web-address: http://www.risoe.dk/amv/

2 Meteorology and Wind Energy Department 1996

2.1 General

The Meteorology and Wind Energy Department has traditionally been seen as consisting of two scientific groups:

1. the meteorology group, carrying out research related to boundary layer meteorology, either aimed at wind-resource estimation or other types of wind climatology or projects aimed at describing transport and flux conditions within the boundary layer, and
2. the Test Station for Wind Turbines, carrying out wind turbine research and technology development, research into application and integration of wind energy, testing, type approval and certification of wind turbines.

In the meteorology group the research is based on fundamental information about mean flow, fluxes, turbulence and transport qualities of the boundary layer in general. The activities however have been organized into two focused programmes:

- Wind Resources and Wind Loads
- Transport and Exchange of Atmospheric Pollution.

The meteorology programmes have a strong synergy. The meteorological research is focused more on the behaviour of the physics of the wind field than is normal for similar meteorological groups, because the wind is traditionally not considered as a very important meteorological parameter. This knowledge of the wind has been an advantage in the transport and flux activity, because real-time description or non-ideal site description of the transport properties of the atmosphere demands highly accurate wind fields as opposed to the more general average descriptions usually employed. On the other hand most groups involved in wind resource or wind load estimates tend to neglect the importance of the thermal forcing on the wind field so important for transport and fluxes. Thus they are not equipped to handle wind problems where such is important, eg for coastal situations.

The activities of the Test Station for Wind Turbines are organized in two programmes and two special tasks:

- Wind Energy Systems
- Wind Turbines
- Type Approval, and
- Test and Measurement.

The strength of combining these programmes with the meteorology programmes is evident, as wind turbines are made to utilize and withstand the wind. The combination is unique when comparing the department to similar international organizations.

By combining research into meteorology, wind turbine technology and wind energy systems with international consultancy on wind energy and the testing, certification and approval of wind turbines the department has a unique and close partnership with the Danish wind turbine industry.

A common trait in all research programs in the department is the combination of analytical methods with full-scale experiments. The result is that the department

has the capability to organize, mount and interpret large boundary-layer field campaigns and wind turbine measurement campaigns to an extent only met by few other institutions in the world.

In the following research highlights from 1996 are presented for the four research programmes together with significant results from the other activities of the department.

2.2 Transport and exchange of atmospheric pollutants

General

The research programme has as objective to develop, evaluate, optimize and apply models for the description of transport, dispersion and exchange of polluting compounds in the atmospheric boundary layer.

The combination of experimental studies with modeling within boundary-layer meteorology and atmospheric dispersion provides possibilities for development of new concepts for use in the assessment of industrial risks, pollution monitoring and environmental research in general. Developed methods will be used to formulate rational boundary conditions for numerical meteorological models. The scientific results are extensively used to solve practical problems.

Flux and concentration of chemically active scalars

Knowledge of the behaviour of chemically active scalars in the atmospheric boundary layer is of great importance in the environmental planning. In an effort to understand how the theory for the flux and concentration of passive scalars must be modified to account for sources and sinks which are not located only at the boundaries (the ground and the top of the boundary layer) a number of experiments in international co-operation have been carried out the last many years. Furthermore theoretical considerations about chemically active scalars have accompanied the experimental activities. Recently a simple theory for a ground-source scalar, which undergoes a first-order chemical destruction in the stationary, horizontally homogeneous, neutral surface layer, has been formulated on the basis of second-order closure. It has been formulated in such a way that there is an analytical solution which, in principle, can be verified experimentally by measuring the concentration of the Radon isotope Rn220 (Thoron) with the mean lifetime 80 seconds since the decay can be used to emulate a relative fast, first-order chemical destruction. The theory predicts in detail how the flux and the concentration decrease with height in the so-called constant flux layer.

Wind fields over inhomogeneous terrain

The LINCOM program for calculation of wind fields over hilly but otherwise homogeneous terrain has been extended to also include the effect of a non-homogeneous surface roughness. In addition to the extra velocity perturbation field this extension also gives the surface shear stress distribution. Within the RODOS framework LINCOM is used to give an intelligently interpolated/extrapolated wind field over the area of interest, and this field is used by the RIMPUFF dispersion program for plume tracking. The new extension is important for: 1) the prediction of the time of arrival of radioactive clouds traversing, for instance, a land/water/land surface, and 2) for calculation of the shear stress related scaling parameters that further control the deposition of radioactive material to the ground.

Surface fluxes of chemical compounds

Together with the Department of Environmental Science and Technology we hosted an international field experiment (FOREXNOX) on ozone and NO_x fluxes to a beech forest (Lille Bøgeskov, Sorø). The partners visiting the site and working there for three weeks in June were from TNO (The Netherlands) and University of Manchester (UK). The primary goal was to investigate the role of bacterially produced NO (emission from the soil) on the amount of the ozone flux. The larger the NO emission the smaller is the actual deposition (damage) to the trees and the foliage. Analysis is in progress.

Another purpose was to investigate the problem of surface temperature parametrization. This temperature plays an important role in heat-flux calculations in transport models. It is often obtained from remote sensing. The averaging of such sensors in relation to the natural variation (nonlinear because the signal depends on T^4) as well as the difference between the radiation temperature obtained.The actual aerodynamic or effective canopy temperature are important problems to be solved. Data from a vertical array of high-precision thermocouples as well as from a number of radiometers were gathered. The data from this part of the experiment will be interpreted in collaboration with scientists from The National Center for Atmospheric Research (NCAR, USA) and Oregon State University (USA).

Water vapour and CO_2 fluxes over forest

The long-term commitment on meteorological measurements on the forest site in Ulfborg has been reinforced on two accounts. So far the deposition-flux calculations have been based on surface-layer profile assumptions (simple measurements of wind speed and temperature gradients). However the system has now been augmented by a sonic anemometer and a software that directly supply information on the friction velocity (u_*) and the Monin-Obukhov length (L), parameters that are needed for flux calculations.

Another new development is a closer co-operation with researchers observing the phenological variations at the forest plot. The goal is to correlate this with extreme meteorological events such as drought and occurrences of early or late frost.

A new long-term commitment has started in Lille Bøgeskov (a beech forest near Sorø Akademi) where we try to determine the carbon and water budget for such an ecosystem. A 57m tall mast has been erected and continuous eddy-flux measurements of CO_2 and water vapour are carried out. The project (EUROFLUX) is funded by the CEC and is part of a world-wide flux network organized under the auspices of BAHC, a project in the International Geosphere Biosphere Programme.

Hopefully the facilities established at Sorø will be able to attract other groups of researchers, for example from plant physiology and soil science.

Surface fluxes in heterogeneous terrain

The background for this work is that large-scale transport or climate models have to be fed with parametrized forms of the boundary conditions. This is because the resolution of such models typically is no better than 100 km due to the limitations of computer capacity. Thus the wealth of variability in the surface conditions on scales smaller than this one must be aggregated.

Our contribution to this research is the development, testing and validation of a microscale aggregation model. The model is based on a simplified advection-diffusion equation that is solved by Fourier techniques. To handle "real" terrain

data a numerical (Fast Fourier Transform) solution is used. Field data of roughnesses and momentum fluxes from various experiments have served to test the microscale model in the well-known situation of a single roughness step change in one dimension. These results are good indeed. In two dimensions the microscale model has been tested with satellite- derived roughness maps and field data of momentum fluxes in the Rhine Valley in Germany. These results compare reasonably (within ± 50% of the field values). Further validation of the calculated spatial flux maps demands spatially measured data such as airborne flux data. Plans on this last step of relevant research is suggested to be based on data from the large-scale experiment in Canada (BOREAS).

A future version of the microscale model allowing calculation of the heat fluxes, water vapour and trace gas fluxes with inclusion of various plant related parameters will be made within a new Danish research project. This project called "Remote Sensing Based Crop Simulation and Soil-Vegetation-Atmosphere Transport (SVAT) Modeling" is performed in co-operation with the agrometeorological group at Research Centre Foulum, the Institute of Geography, University of Copenhagen, the Danish Hydraulic Institute and the Royal Veterinary and Agricultural University of Denmark. The project involves long-term flux monitoring in Jutland, satellite analysis and flux modeling.

Satellite imagery for surface fluxes

Satellite images can be used to derive some surface characteristics that are essential for estimating surface-atmosphere fluxes. In heterogeneous terrain only satellite images can provide the necessary information with a reliable degree of precision. Important are surface roughness maps and surface temperature maps. Roughness maps were obtained from classified optical and radar images in the Rhine Valley within the EUROTRAC TRACT project. The satellite data from Landsat TM and ERS SAR were combined with meteorological data from the area. These roughness maps were used as input to the microscale flux aggregation model. Airborne data and satellite data will form a basis for the calculation of fluxes in the Danish SVAT modeling interdisciplinary project.

Scalar fluxes measured by eddy correlation

When measuring turbulent fluxes of scalar quantities in the atmospheric surface layer, the eddy-correlation method is the most basic, relying on first principles only. Eddy-correlation measurements are typically carried out using a fast sensor for measuring the scalar (temperature, gas, aerosol) and a fast anemometer, eg a sonic anemometer to measure the fluctuating vertical wind component. This method relies on the assumption that the scalar signal and the velocity signal can be considered as pertaining to the same point in space. Most often this assumption is violated and an effort has been made to determine the importance of the anemometer and scalar sensor not being co-located. Qualitatively the systematic error in the measured flux must be an increasing function of the ratio of the sensor displacement and the scale of the turbulence. This implies that the effect of a given displacement is more important close to the ground than at larger heights. Covariances of temperature and vertical velocities were measured with sonic anemometers close to the ground at two locations: Boulder in Colorado and Risø. These measurements and theoretical considerations show that when the separation is horizontal, the 'flux loss' is independent of the orientation of the displacement vector with respect to the wind direction. It was found that a 0.2 m horizontal separation will give rise to a loss of 1% at a height of 10 m and a loss of 13% at 1 m. Theory and the measurements also showed that there is an up-down

asymmetry when the sensor separation is vertical: the loss is smaller when the scalar sensor is mounted below the anemometer than when it is mounted above it. Measurements at the mean height of 1 m showed that the loss of flux for a separation of 0.2 m is 2% in the first case and 18% in the second. The conclusion is that when measuring close to the ground, the separation should be vertical with the scalar sensor below the anemometer. In this way a symmetric (omnidirectional) configuration with a minimum of flux loss is obtained.

Odour and concentration fluctuations

The SMP project entitled odour and concentration fluctuations was set out to conduct a series of repeatable and well-documented dispersion studies, that in particular should focus on the fast-changing and stochastic nature of the peak concentrations that can be observed on a second-short time scale in the vicinity of many point sources.

This project jointly conducted by Risø-AMV/DMU-ATMI and dk-TEKNIK has successfully provided new sets of high-resolution experimental data on the fast and ever-changing stochastic nature by which puffs and plumes, and therefore also for the spread of malodorous gases, spread in the air by wind and turbulence.

In addition to a successful conduct of the experimental campaigns, and to the establishment of a corresponding quality assured data base that now holds more than 100 diffusion tests, the project has in addition provided new and practically applicable statistical models, some of which have already been evaluated and proven useful for predicting the statistics of the observed peak concentrations. For a given hour, and depending on the meteorology, one statistical model can predict the number of expected excursions over a predefined critical concentration, and it can also predict the number of seconds or minutes where this level (on the average) will be exceeded. This statistical model is therefore also practical applicable to predict the expected number of excursions, and their duration, of a critical load factor for odour. The same model however is also applicable for assessing critical doses and toxicological effects on flora and fauna.

The experimental data base holds high-spatial and temporal concentration measurements obtained from dispersion experiments that were conducted under a variety of different meteorological conditions, some even including the effluence of nearby buildings, and others performed from elevated and ground-level based sources. During the measurement campaigns the measuring points were always selected as representative for realistic local-scale source receptor constellations.

It is the belief of the team, that the successful conduct of this project has now provided the Danish society, including its governmental agencies and industry, with an unique experimental data base and a corresponding modelling capability, that is suitable for assessing the statistics of concentration fluctuations even on the shortest time scale relevant for air quality.

Further strategic application of our results exists by combining resulting statistical models (for short-time exceeding of critical levels) with already existing air quality models for (hourly) mean concentrations (eg the two Danish OML or RIMPUFF models), and following this way we can establish new and better methods for assessing the statistics of the short-term high-level air concentrations on a rational basis.

Field experiments

Our SMP-programme involved several experimental measurement campaigns: three experiments over flat terrain (Borex '92, Borex '94 and Borex '95), one building wake diffusion experiment (Borsele '93), and two smaller in-situ measurement

campaigns (St. Merløse, '94, and Mesinge '95).

During the Borex trials a series of atmospheric dispersion experiments were conducted that were based on combined SF_6 tracer gas and aerosol backscatter lidar technique.

Selected experiments made use of two (almost) identical mini-lidar systems for aerosol cloud detection to test the reproductiveness and uncertainty of lidar techniques for measuring plume contractions. Simultaneously tracer gas measurements were compared with the two lidar systems.

The lidar measurements based on remote sensing were found to give reproducible results within 15% and the correspondence with the in-situ tracer gas measurements was excellent, cf. Jørgensen et al., (1996). The new technique of using joint lidar and tracer gas studies, not only for the plume width and mean concentration, but also for concentration fluctuations, have in this way been established.

Based on the set of plume diffusion experiments a comprehensive data base has been established.

The data base has been quality assured and analysed with respect to the following important dispersion quantities: mean and variance concentration profiles, intermittency profiles and exceedance and duration statistics including pdf's and cdf's, determined at several downwind distances from the source.

All campaigns were accompanied by detailed micro-meteorological measurements of all relevant mean and turbulence quantities.

The Borsele'93 building wake dispersion experiment (Scholten et al., 1994) showed that the standard plume correction methods underestimated the down draft of the plume centre line in the building wake.

The Borex experiment shows significant difference in plume concentration statistics depending on source height (elevated versus ground releases). Also in connection with strong insolation on hot summer days we have experienced short-time peak concentrations up to $\sim$ 40 times higher than the (hourly) mean concentrations.

The Mesinge campaign assisted Danish pig breeders during an investigation of minimizing odour annoyances from ventilating piggeries.

Modelling

On the modelling side of the project, a formula-based model has been developed to describe the concentration statistics for short exposure times (about one sec). The model can be used for assessing odour problems from both elevated and ground based point sources (Løfstrøm et al., 1995).

The model is designed for operational use by decision-makers. It describes the cross-wind and down-wind distribution of concentration fluctuation intensities and the parameters of the cumulative distribution functions. It accounts for source height and dimension, atmospheric stability, and downwind distance.

The model is developed and tested on different subsets of the Borex data base.

Because our study is based on full scale atmospheric dispersion experiments, this model features meander and stratification effects that are not contained in wind tunnel studies, on which most previous concentration fluctuation models have been based.

2.3 Wind resources and wind loads

General

The objective of the programme is to develop, verify and apply numerical models for wind resources as well as to determine and model wind loads on wind turbines and civil engineering structures.

Experience with experimental and theoretical boundary-layer meteorology is the basis for development of concepts to determine wind resources and wind loads. Improved siting criteria for wind turbines provide the basis for balancing energy potential versus the structural lifetime. The scientific results are extensively used to solve practical problems.

Prediction of wind farm output

In areas with a high percentage of wind energy connected to the electricity grid, problems of sudden drops or increases in power production occur. In addition it is very difficult to actually save conventional energy without knowing well in advance (ie up to 36 hours) the expected production of power from wind energy. Under the EFP programme the Ministry of Environment and Energy has initiated a project co-ordinated by Risø, where Risø together with partners from the Danish utility ELKRAFT and the Danish Meteorological Institute (DMI) are implementing a model to forecast the power produced by the major wind farms on the islands of Zealand and Bornholm. The model was run operationally for a full year at DMI producing forecasts. The project is now finished and the verification against the actual power produced by the wind farms showed that the model performed very well compared to models used today and also to predictions made by the dispatchers at the utilities. The model is now being implemented in Denmark, England, Greece and USA in a EU-JOULE3 funded project running from 1996 to 1999.

Wind atlas for Russia

A first attempt is now being made to map the wind resource of Russia. The work is carried out as a co-operation between Risø and the Russian-Danish Institute for Energy Efficiency in Istra outside Moscow. To get information in an efficient way for this vast country all available digital information must be used. The first very coarse results show that high wind resources are typically found in the northern areas and also in some specific area in other parts of the country. The atlas – which will be written in Russian of course – is expected to be ready in the middle of 1997. The project is funded by the Ministry of Environment and Energy.

Turbulence in complex terrain

Turbulence over flat, homogeneous terrain is quite well understood. However many wind turbines and other man-made structures are situated on top of hills or close to the coast where the character of the surface changes drastically. On the basis of models and experiments of the turbulence over idealized hills and over simple changes of surface characteristics, we are developing a general model of the turbulence over an arbitrary terrain. The basic idea of the model is to calculate the modification of the turbulence due to the changes in the mean flow induced by the terrain. Despite its simplicity it compares well to the Askervein experiment and comparison with other experiments (eg Sky River) is underway. A preliminary version of the model is incorporated in the WA^{S}P model complex while later versions are using another of our linear flow models: LINCOM.

Precision of wind-resource prediction in complex terrain

The Wind Atlas Analysis and Application Program WA^{S}P is known to give accurate predictions in terrain with smooth hills sloping sufficiently gently to ensure attached flows. Out of necessity WA^{S}P is often used also in complex, mountainous terrain with steep slopes, in which case overprediction of the wind resources may occur. A study has therefore been performed to assess the prediction error in complex terrain and to relate it to some suitable terrain characteristics. The study was based on three and a half years of wind measurements from six stations with varying terrain steepness, situated in the coastal mountains of northern Portugal. The WA^{S}P representation of the difference in wind climate between sites within the same wind regime, but in different terrain, was compared to the measured wind data for all site pairs among the six stations. The data from the Portuguese stations suggested that a suitable terrain characteristic for the prediction accuracy would be a "ruggedness index", based on the extent of terrain within about four kilometres from the site, with slopes higher than a typical flow detachment limit. The difference in such a ruggedness index seemed to correlate well with the prediction error in magnitude as well as in sign, even for errors in the mean velocity as high as 20%. The work will continue, using data from other complex terrain stations to confirm the ability of the ruggedness index to give an estimate of the prediction accuracy of WA^{S}P in complex terrain.

2.4 Wind energy systems

The objective of the programme is to develop numerical models for analysis and design of electronically controlled wind-power station application and integration into energy systems. The programme has four parts: 1) electro-mechanical components, 2) control systems, 3) large-scale integration of wind power and 4) hybrid energy systems.

The activities on electro-mechanical wind turbine components and control systems shall be viewed in the light of the international development of new wind turbine concepts. The activities on large-scale integration and hybrid systems is of a special importance to the implementation of wind energy in Denmark by the power companies. In addition to this they support our consultancy services to Danish and international authorities, organizations, banks and investors.

Power control for wind turbines in weak grids

In a project funded by the EU and coordinated by Risø a new power control concept for wind turbines is being developed, which makes wind power more firm and enables connection to weaker grids. The main options are to combine wind power with a pumped hydro power storage or with an AC/DC converter and battery storage. The AC/DC converter can be either an "add-on" type or it can be designed as an integrated part of a variable-speed wind turbine. When the power control concept is matured, the expectation is that for certain wind power installations the cost of the power control may be paid back as added wind power capacity value and saved grid reinforcement costs.

The project comprises concept development, prototype testing and case studies. The concept is developed by applying existing simulation models. To gain actual hardware experience a 50 kW, 30 kWh "add-on" power control prototype has been developed by ABB (NO) and is now installed for testing purposes at Risø. The test program includes performance assessment and monitoring of operating conditions under real life conditions and for various control strategies.

Case studies are conducted for Madeira (PT) and County Donegal (IE). Both areas have favourable wind conditions and limited grid capacity for excessive utilization of wind power. The case studies analyse and suggest solutions for efficient use of wind energy in the power system by applying the power control system. Follow-up demonstration projects utilizing the power control concept are anticipated.

Feasibility studies

As a consequence of the technological development in wind energy and the growing market, the demand for accurate wind farm feasibility studies is increasing. Requirements to feasibility studies are developing because of increasing wind farm sizes and their impact on power systems. The department is developing feasibility study methods and tools for the necessary in-depth analyses ranging from wind resource assessment (WASP) and wind-farm array layout and energy production estimation (PARK) to power system analysis (WINSYS) and economic analyses and cost of energy calculation (COSTEST). The development of these tools is a continuing process which is very much governed by the interaction with various clients and projects based on our wind energy research and the development world-wide.

A number of such wind farm feasibility studies are being implemented, utilizing the Risø feasibility study tools. The following studies were completed in 1996:

- the wind farm feasibility study in Cape Verde, recommending a phase 2 project expanding the installed wind farm capacity from 15 to 25% annual wind energy penetration. The study included complete power system analyses of the three isolated main power systems on three different islands in Cape Verde;
- the establishment of a demonstration wind farm in Syria was studied, including site selection and wind-resource assessment. A promising wind energy potential and land for large wind farms were identified, and a demonstration project was found feasible and formulated;
- the assessment of an existing wind farm and a feasibility study of two proposed wind farm projects on preselected sites in the Czech Republic were studied directly at the request of the potential funding agency.

The studies were funded by Danida, UNDP, the Danish Ministry of Environment and Energy, the EU APAS Programme and others.

2.5 Wind turbines

The objective of this programme is to develop calculational models for analysis of wind-turbine aerodynamic and structural properties and to design wind turbines. The program comprises: 1) advanced blades; 2) aerodynamics and aeroacoustics; 3) aeroelasticity and loads; 4) new concepts; 5) experimental verification, and 6) structural design. The activities are of special relevance to the technological development in the Danish wind turbine industry and the international competitiveness.

Improved blades

An important objective of Risø's Wind Energy Programme is the improved design of wind turbine blades resulting in better performance and less noise. In Risø's

contract with the Ministry of Information Technology and Science some criteria of success are mentioned: a 10% minimum improvement of best existing blade design and establishment of a collaboration with wind turbine producers on manufacturing and testing of a prototype within the contract period. These criteria of success have been reached in 1996.

A recently developed numerical optimization tool and an aeroelastic code have been used in our research. The results indicate a potential improvement of about 11% in the cost performance of which 5.5% can be achieved by use of traditional airfoils. By use of a new generation of specially tailored airfoils the improvement was found to be around 4% of the annual energy production and 1.5% of material consumption.

The research was partly funded by the Danish Energy Agency.

Rotor diameter investigation

The change in wind-turbine rotor power obtained by increasing the rotor diameter and using blade extenders has been investigated with the 3D Navier-Stokes solver EllipSys3D. The Ellipsys3D code is developed by Risø in collaboration with the Department of Fluid Mechanics at the Technical University of Denmark. The inputs necessary for computation are blade geometry, rotor radius and RPM of the wind turbine. In good agreement with measurements it was found that the increase in rotor power was only half the amount expected from enlargement in the rotor area.

The research was partly funded by the Danish Energy Agency.

Experimental verification of airfoils

A procedure for wind-tunnel testing of airfoil sections has been developed for both static and dynamic conditions. Together with weight cell measurements, pressure measurements on the airfoil and in the airfoil wake reveal the aerodynamic properties. The aim is to develop the tools necessary to test new airfoils for wind turbines including model manufacturing, wind tunnel testing and interpretation of results. So far the NACA 63215 airfoil and a new 13% airfoil developed at Risø were tested. Good agreement with calculations and other experimental investigations was found. The new 13% airfoil shows very promising stall characteristics and roughness insensitivity. Measurements of dynamic behaviour from pitching motion show the expected stall hysteresis loops to be used in the development of dynamic stall models. The work was partly funded by the Danish Energy Agency.

Stability under stall

The stability of wind turbine blades under stalled conditions has been investigated. The stability phenomena are controlled by a wide range of parameters, and the research concentrates on identification of the main parameters by use of measurements and aeroelastic simulations. Several parameters have been identified. An example of an important parameter is the orientation of the principal bending axis along the blade, which determines the actual mode shapes of the blade.

The research has partly been funded by the Danish Energy Agency and the EU JOULE Programme.

Partial coefficients for wind turbine design

A strong rotor is of vital significance for a wind turbine in order to avoid serious damage; however a strong rotor is very expensive. Precise methods for choice of

a correct rotor strength is therefore of great importance. In wind-turbine standard specifications the partial coefficient method is the one generally applied. For a wind-turbine designer this method is simple. It includes the so-called partial coefficients, but they rather present a research problem. To a large extent the coefficients in question influence directly the strength conditions required. This means that eg a 20% increase of a partial coefficient will demand also 20% of the strength conditions. In a co-operation with Det Norske Veritas (DNV) Risø has performed a project defining the partial coefficients necessary to calculate the dynamic strength of a rotor with blades of glass-fibre reinforced plastic. Risø has prepared also an overview of wind-turbine partial coefficient problems in co-operation with DNV and other European research institutions. The projects were funded in part by the Danish Energy Agency, Energy Research Programme, and EU Joule Programme.

International standardization of wind turbines

Danish Industry has made wind turbines an important Danish export article. A large export trade may easily be bothered by "technical trade barriers". To avoid such barriers Risø participates actively in developing international standard specifications for wind turbines. Risø is eg chairman of TC88, International Electrotechnical Committee and a task force BTTF83-2 under CENELEC. In addition to this Risø is convener of various task groups concerned with detailed standard specifications. This activity is supported and funded in part by the Danish Energy Agency.

2.6 Type approval and certification

Since 1979 Risø has been authorized by the Danish Energy Agency to approve wind turbines. Today the area of approvals is deregulated and we offer type approval and certification as a commercial service to the international wind-turbine industry. Risø is accredited by DANAK according to EN45001, and our type approval and certification activities are organized in a separate organizational entity as prescribed by the accreditation authorities.

For several years now we have had a co-operation with Det Norske Veritas (DNV) on type approval and certification on an international level.

Among our services is "one-stop-stopping" type approval procedure, where type approvals for several markets are issued in one process. This means that DNV and Risø can issue type-approval certificates according to national rules in The Netherlands and in Denmark and a "Gutachten" according to national rules in Germany. Furthermore a type approval issued by DNV and Risø is accepted by the authorities in Sweden, Norway, Greece, India and other countries.

In order to carry out the activities required for a type approval, Risø and DNV are qualified within the following areas:

- meteorology
- aerodynamics
- aeroelasticity
- probabilistic design
- material technology
- machinery
- structural design

- testing and measuring methods
- inspection methods
- quality systems.

Type approval is recommended for wind turbine types in serial production. Type approval is a verification of the wind-turbine design according to an approval scheme. This scheme may be extended to cover specific national requirements.

Certification is applicable for a single wind turbine as well as for a complete wind-turbine project and its operation. The certification of a project may include verification activities during all stages of the project. A certificate is issued for a complete project which is found to comply with the agreed requirements. The certificate may be maintained during operation through periodic surveys and audits.

ISO 9000 is an internationally recognized quality system standard. ISO 9001 and ISO 9002 are relevant to wind turbine industry. ISO 9001 specifies quality system requirements for design, development, production, installation and servicing. If no design and development are involved, then ISO 9002 is to be applied. It specifies requirements for production, installation and servicing. A world-wide certificate for quality assurance should be accredited, ie approved on a national basis according to eg one of the schemes to which DNV is accredited, at present fourteen different accreditation schemes.

2.7 Tests and measurements

The test and measurement activities at Risø comprise three main areas: 1) accredited testing in relation to certification of wind turbines; 2) measurements intended for experimental research and verification of models, and 3) participation in developing an international standardization on test and measurement procedures for wind turbines and blades.

Risø offers accredited testing of wind turbines and major components (eg blades) as a full commercial activity on a scientific basis in relation to certification of wind turbines in accordance with the Danish Certification System. Risø is accredited by DANAK according to EN45001. The testing activity is a separate organizational entity as prescribed by the accreditation authorities. This activity is carried out according to both Danish and international standards (eg IEC). The following test activities apply to the Danish Certification System:

- power performance measurements
- basic test of wind turbines
- system test of wind turbines
- conceptual test of wind turbines
- static blade test
- dynamic blade test
- fatigue blade test
- calibration.

Risø also offers testing according to certification schemes valid in other countries, for example Germany and The Netherlands.

Risø's experience in wind turbine testing dates back more than 20 years, and an important activity has been to develop and improve measurement procedures. Based on this experience we participate in most aspects of national and international standardization in this area (eg within the framework of CENELEC, IEC, and IEA).

2.8 Measurement techniques

The department constantly runs a large number of field experiments as well as long-term monitoring activities. These activities, although being part of the meteorological research programs by themselves, occupy a staff of two scientists and seven technicians constantly working within the various projects and with developing and maintaining instrumentation. Two themes have dominated meteorology measurement developments in 1996, the implementation of new techniques for flux measurement and the design and commissioning of a new "embedded" data acquisition system.

Flux measurements

Our flux measurement repertoire has increased with the addition of continuous measurements with a closed path system and relaxed eddy accumulation. Both methods have entailed significant development of both software and hardware.

Closed-path measurements

Measurement of a flux using a closed-path instrument requires transporting a sample of the air through tubing to the sensor for the required species (eg water vapour or carbon dioxide). The air is sampled close to a sonic anemometer which measures the vertical wind speed fluctuations. Typically the sensor is situated many metres from the sample point, for example in a hut close to the base of the measuring mast. Given this distance, it is important to ensure that the fluctuations of the species arrive at the sensor without undue filtering. This is essentially a hardware challenge, met by ensuring sufficient flow rates and by careful plumbing.

Another implication of the distance between the sample point and the species sensor is that the concentration measured by the sensor will be delayed in relation to the speed fluctuations measured by the sonic anemometer. In practice this delay will vary somewhat and can not be assumed constant. This complicates determination of the flux, requiring separate flux calculations over a range of possible delay times.

For continuous measurements, these calculations should be performed on-line, since manual post-processing of the data would be extremely time consuming. This was a significant software challenge, met by adding a new object oriented, real-time interface to our existing DAQ data acquisition software. The new architecture allows external programs to respond to any data acquisition event, ranging from a raw scan to completion of a run. With these facilities it was possible to write a program that continuously updates the covariances for all the required lags, transforms the covariances into a coordinate system aligned to the mean wind and removes the effects of linear trends on the data.

Relaxed eddy accumulation

This is a so-called "conditional sampling" technique in which air is sucked or blown into one of two repositories (or sensors) according to the sign of the vertical wind speed. A concentration difference between the two samples corresponds to a vertical transport of the species. By measuring (or simulating) the concentration difference of a scalar whose flux is at the same time measured by eddy correlation, it is possible to relate concentration differences to a qualitative flux. Relaxed eddy accumulation is suitable for measuring fluxes of species for which rapidly responding concentration measurement in the field is not possible.

Switching of the air into the required up or down repository is achieved using

fast responding valves. In order to reduce valve cycles and at the same time give a larger concentration difference, the valves are only opened if the absolute value of the vertical wind speed exceeds a given value (usually a fixed fraction of the standard deviation). The valve to be opened is then determined by the direction of the speed (up or down).

In practice the vertical wind speed measured by a sonic anemometer is very often contaminated by tilting (of the instrument or the terrain) and by flow distortion. We have sought to remove this error by performing a continuous, sector-wise linear regression of the vertical speed onto the magnitude of the horizontal speed. This results in a tilt angle and speed offset for each sector (typically 5 degrees wide) which is then used to correct the instantaneous vertical speed. For this and for the software control of the valves, we have utilized the real-time interface of our DAQ data acquisition software as described above.

Embedded data-acquisition systems

Data acquisition in field experiments has typically used conventional PC equipment coupled to terminal boxes performing termination, surge protection and signal conditioning. An "embedded" data acquisition system is one in which the data acquisition computer is built into the terminal box, saving space and eliminating the untidy and unreliable connections between the terminal box and computer. In such a system, the computer is a miniaturized, low power and industrially hardened version of a conventional PC, allowing "legacy software" - our existing DAQ data acquisition system for example, to function virtually unaltered.

The need to realize such a concept arrived with our involvement in a survey of the offshore wind resource in south-east Denmark. This project required self-contained measurement systems that could be supplied from small battery-charging wind turbines. A variety of sophisticated wind and wave instrumentation was envisaged and this precluded use of existing low power data logger systems. Our DAQ software would be ideal however, since this combination of instrumentation had already been tackled with a conventional PC system.

In conjunction with colleagues in the Computer and Engineering Department, we have developed a modular system comprising an embedded PC and a terminal box in which this can be mounted. Together this forms the embedded data acquisition system. The modularity is making virtue of necessity. Electronic noise regulations require the PC to be completely screened. This is most readily accomplished by mounting it in a separate box, forming a complete faraday cage. Many applications require little or no additional signal conditioning and in such cases the embedded PC alone can be used, for example mounted on the rotor of a wind turbine.

Several new technologies have been employed in the design of the embedded system. The PC is built up using components connected on the so-called pc104 bus, a compact and low-power version of the standard PC "AT" bus. PC-card (pcmcia) technology, popular from portable PCs, is used for data storage since this has the advantages of small form factor, low power consumption and ease of replacement. Flash memory (solid state and non-volatile) is available for capacities up to 40 Mbytes. PC-card hard disks (currently up to 260 Mbytes) may also be used (at the expense of extreme reliability) if a significantly greater storage capacity is required. Communication using GSM (digital mobile telephone) technology has been employed for the offshore masts although conventional analogue modems can be readily substituted for land-based systems.

2.9 Facilities

Three wind turbines for experimental aerodynamics and structural dynamics are in operation at Risø: a Tellus 100-kW, a Nordtank 600-kW and a two-bladed, dynamically flexible research machine.

Risø operates a blade testing facility at Sparkær in Jutland. This facility includes an indoor rig for dynamic and static testing of blades up to 50m. Also our accredited blade testing is carried out at this facility. The test facilities available for fatigue and static test are shown in the table below.

	blade length [m]	static load maximum [kNm]	fatigue load maximum [kNm]	BCD Maximum [mm]
A	44	20 000	10 000	3 000
B	44	6 000	3 000	2 000
C	44	6 000	3 000	2 000
D	34	3 000	1 000	1 200
E	14	1 000	500	1 200
F	6	1 000	300	1 000
G	10	500	200	600
H	21	2 000	—	1 200

In addition we have other special facilities at Sparkær:

- a fibre laboratory with high-temperature oven to determine fibre orientation and fibre content;
- equipment to record the blade airfoil shape and twist angle;
- cooling and heating facilities to expose a full-scale blade test with temperatures in the range $-25°C$ to $+80°C$;
- a fibre glass shop producing sample laminates,
- a constant deflection testing machine for dog-bone shape sample testing.

In 1996 a new 1250 square metre testing hall has been erected. This new facility enables us to perform static as well as fatigue testing of blades with a total length of 45 m. Six testing stands are at hand. A combination of flapwise and edgewise fatigue loading will be introduced. In comparison with the system used till now a reduction of the testing period by one third is expected. This is because pre-loading will no longer be applied.

Finally a facility for wind turbines in hybrid systems is in operation at Risø: a Bonus 50-kW wind turbine, a diesel generator, a flywheel, photovoltaic panels, battery storage and controllable loads.

2.10 Organizational development

Risø's general research strategy, "Risø 2000", was reviewed in 1996 and a new strategy was formulated. As a consequence of the new strategy and in order to harmonize management and organizational structure within Risø, the department prepared a proposal for new programs and special services to be implemented by the beginning of 1997. Simultaneously the department will change its name to "Wind Energy and Atmospheric Physics Department".

As a result of expressed industry needs more emphasis will be put on power electronics, electrical machines and control. The research will be organized in the research programs:

- Atmospheric Transport and Exchange
- Wind Power Meteorology
- Aeroelastic Design
- Electrical Design and Control
- Wind Turbines

Special services are the following:

- Wind Turbine and Blade Testing
- Type Approval and Certification
- Experimental Meteorology

The resulting organization in the department is shown in the figure below:

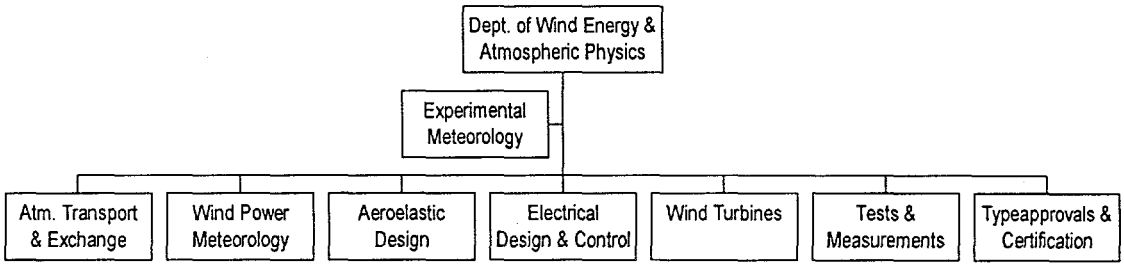

Figure 1. Organization of the department in 1997.

3 Key Achievements

The research achievements in two key areas of the department have been selected for further presentation. The first one, achievements in wind turbine blade design, has been also one of Risø's success criteria during the contract period of 1994-97 while the second, research on atmospheric fluxes over biosystems, represents the result of a long-term micrometeorological research effort which has found renewed interest within the context of climate effects and the interaction between atmospheric pollutants and the ecosystems.

3.1 R&D achievements in wind-turbine blade design

An important objective for Risø's Wind Energy Program is the improved design of wind turbine blades resulting in better performance and less noise. Risø's contract with the Ministry of Research and Information Technology mentions a criterion of success: a 10% minimum improvement over best existing blade design and establishment of a collaboration with wind turbine producers on manufacturing and testing of a prototype within the contract period.

A range of R&D projects have participated in achieving this target. The results indicate potential improvements measured in an overall cost reduction in DKK/kWh for power produced by wind turbines. The comparisons are based on a 1991-1993 state-of-the-art 500-kW wind turbine.

Source of improvement	Relative improvement in DKK/kWh
Utilizing optimization tools in general	2.5%
Improved material data	5%
Optimized cut-off wind speed	3%
New, advanced airfoils	5.5%
Reduced extreme loads by better control strategy	11%

Together these relative improvements exceed the criterion of success mentioned above. Elements of these potential improvements have been implemented in the latest machines produced by Danish wind turbine industry, but it is impossible to to calculate exactly how much. This would require 'copying' of a full commercial machine into a new, optimized version. However the Association of Danish Wind Turbine Manufacturers estimates that a modern 600-kW to 750-kW machine is 15-20% more cost-effective than the 500-kW machines from the early nineties. The progress has been realized partly through research activities. This and other related results are the outcome of a number of research projects at Risø National Laboratory within aerodynamics and structural dynamics focused on subjects closely related to wind-turbine blade design:

- **airfoil design and rotor optimization** was the main subject of a collaborative project initiated in 1989 between University of Southampton, University of Athens and Risø based on funding from the EU DG12 Joule Programme and the Danish Energy Research Programme (EFP)
- implementation and test of the necessary advanced **software for airfoil design** was the specific subject of a project funded by the Danish Energy Research Programme (EFP)
- **experimental investigations and verification** were introduced in 1994. It was then decided to establish a wind-tunnel test facility for airfoils in Denmark using the large 4×4 m tunnel built an operated by the company Novelco (Velux)
- **codes for simulation** of wind-turbine structural dynamics have been further developed in projects funded by the Danish Energy Research Programme (EFP) and EU DG12 Joule Programme.
- The **interdisciplinary national key project 'blade design'** (vingedesign) under the Danish Energy Research Programme was started in 1995. Participants are: Risø National Laboratory (Department of Meteorology and Wind Energy/ Department of Materials); Technical University of Denmark; Elsam-Projekt A/S; Vestas Wind Systems A/S; LM Glasfiber A/S. Some of the activities mentioned above have now been continued within this project.

The first phase of the 'blade design' project consisted of a preliminary study and the work concerned a wide range of investigations in connection with wind-turbine blade design. Among topics of the project are: airfoil design, aerodynamic

noise, power control strategies, rotor optimization, blade vibration parameters, stability of blade shells, structural elements, structural differences between thick and thin laminates and damage resistance of different materials. For each field the state-of-the-art was described, new concepts and ideas were found and preliminary investigations were carried out in order to identify the potentials for improvement of the foundations for wind-turbine blade design. These investigations led to a detailed plan for the next phases in the project, where the focus is on aerodynamics/aeroelasticity and blade materials. The first phase of the project concerned the full blade design process and the work was carried out with the objective of designing a wind turbine rotor. Through this process the critical parts of the blade design process were identified and these parts are the subjects of the remaining part of the project:

1. experimental verification of thick airfoils
2. development of a new series of profiles with high $C_{\ell(\max)}$, low noise emission and low sensitivity to roughness
3. reduction of aerodynamic noise
4. reduction of extreme loads
5. development of numerical optimization tools
6. material strength and stiffness
7. material fatigue, and finally
8. material damping.

Thus the focus of the project has been changed from the overall blade design process to development of tools in the blade design process. The results can be implemented directly into the ongoing blade design and development process in the projects of the industrial partners.

Airfoil design

Design of airfoils for wind turbine use is important for improved blade efficiency, lower blade weight and reliable stall regulation. So far most of the airfoils used were originally developed for airplane wings, but recently airfoils especially tailored for wind turbines have appeared in literature. Compared to airplane wings wind turbine blades experience much more off-design operating conditions. Important parameters in the design of airfoils are high relative thickness for structural reasons; insensitivity to surface roughness for improved performance in dirty conditions; low noise emission; reliable stall when used with stall regulation; good aerodynamic characteristics to improve blade efficiency. The requirements are in mutual conflict. A recently concluded research project involved design of a new airfoil. The design philosophy made use of the XFOIL code with inverse design routines. Special attention was given to roughness insensitivity and reliable stall characteristics. The resulting airfoil, Risø-1, was tested on a full-scale 20-kW rotor, showing high power quality with reliable control of peak power. Furthermore the airfoil was tested in a wind tunnel (see below).

In the 'blade design' project an optimization methodology for multi-point airfoil design is being developed. The goal of the design is thick airfoils with good/acceptable aerodynamic qualities and low noise emission. The design philosophy is simultaneous constraints on both structural and aerodynamic properties including off-design performance to meet the requirements for wind turbine use. The design process is still going on, and so far the method has shown promising results in several test cases.

Wind tunnel experiments

To enhance the understanding of the complex flow on wind turbine blades and to test developed airfoil sections under both static and dynamic operating conditions, a wind tunnel test method has been developed. In a recently concluded project a LM-8.2 blade was tested under both static and dynamic conditions. The 2D airfoil section test method involves a 'Scanivalve' pressure measurement system which presently has 128 pressure tabs. In order to test airfoil sections under 2D flow conditions, a test rig was developed for the Velux 4×4 m open-jet wind tunnel. Furthermore a procedure for manufacturing and instrumentation of the test sections was developed. Requirements were limited costs and a relative short period from airfoil development to test period.

In the present stage of the 'blade design' project the tunnel wind conditions and calibration of results were investigated based on the results obtained, and the test facility is now ready for use. The next work in the 'blade design' project will concern tests of three thick airfoils used on the inner part of modern Danish wind turbine blades. Finally the airfoils developed can be tested by the end of 1997.

Blade tip design

Design of the blade tip region is an important part of the complete blade design process. This is owing to the considerable influence from this region on the total aerodynamic and aeroacoustic characteristics of the blade. In a recently concluded research project partly carried out within the 'blade design' project, a detailed analysis of the flow around different tip shapes has been computed using CFD. The flow mechanism from the blade tip tapering has been clarified showing the principal difference between tapering from the leading edge towards the trailing edge (the trailing edge straight) or reverse. A strong tapering from the leading edge will result in flow comparable with the flow over a delta wing with separation close to the leading edge.

Use of the rotor optimization procedures described above within the tip region will in general lead to a rather slender blade with a tapering of the chord almost to zero at the blade tip. However from acoustic considerations it is not desirable to go below around 20-cm chord for a blade tip speed of 60 ms^{-1} as this can cause problems with laminar bubble shedding.

Noise and aeroacoustics

Almost all acoustic models developed for wind turbines so far are based on a semi-empirical approach. Such a model has recently been implemented and verified at Risø. However a parallel PhD work, Computational Aeroacoustics (CAA), has been carried out on the development of a full numerical approach. The main self-noise sources are modelled by the semi-empirical noise model:

- noise from the turbulent boundary layer passing the trailing edge
- noise from separated flow
- laminar boundary layer vortex shedding noise
- tip vortex noise
- trailing edge bluntness noise.

In addition to the above also the important noise from the turbulence in the inflow to the blade is modelled. A verification of the semi-empirical model has

been made by comparison with different full-scale measurements. The influence of parameter variation has been investigated and in general the correlation obtained is satisfactory.

The noise model has now been integrated in the optimization tool described above and constraints on the noise can be introduced during the design optimization. A more detailed study of the tip noise has been carried out in parallel to the aerodynamic studies of tip design described above. The noise is caused by the separating tip vortex, and a main result of the study is a design for a new "low noise emission" tip with a non-separating tip vortex (the NSTV tip).

Structural dynamics/stall-induced vibrations

For the stall-controlled wind turbine an aeroelastic instability problem – stall-induced vibration – can occur. Damping originating from the aerodynamic loading can be negative for a certain operational range of the wind turbine. If this results in a negative total damping of the wind turbine blades, excessive vibrations in the blades can occur. For modern wind turbine blades the optimized stiffness and strength ratio result in a relatively low structural damping, and the problem with stall-induced vibrations can be severe. The latter has been the subject of both national and EU funded projects. Through these projects the main parameters for the stall-induced vibration problem have been identified. These main parameters can be divided into three categories:

1. blade profile characteristics
2. blade structural characteristics and
3. wind-turbine structural characteristics.

The latter illustrates that the blade vibration problem is related to the overall wind-turbine dynamics, ie it is necessary to consider the turbine in all its aspects and not only to concentrate on the blade characteristics. Work is carried out with the objective of implementing the results in aeroelastic load prediction models in order to be able to predict the vibration levels and to design blades and wind turbines without this problem.

Rotor design/numerical multi-point optimization

There is a tradition for single design point methods in the aerodynamic design of rotors, that do not directly take into account the magnitude of the design given load cases. The resulting design has optimum efficiency at some design wind speeds or at some wind speed intervals depending on the type of power regulation. However the operational conditions include a large wind-speed interval and several important fatigue and extreme load cases. These load cases affect the entire wind turbine, and hence the design of the rotor should include load-case control. Therefore a numerical multi-point optimization tool was developed. The optimization objective is directly taken as the kWh price including the cost of all main components. This objective is more representative compared to aerodynamic efficiency or specific energy production. The cost is estimated from the design given loads and allowable material properties. When furthermore constraints are put on material properties, if possible, these are used to the limit, resulting in lighter components and hence lower cost.

The design tool includes calculation models for important load cases, eg fatigue loads (from time simulation and rainflow counting) and extreme loads from codes of practice, concerning extreme operational conditions at extreme wind speeds.

In a recently concluded project a design study was carried out concerning a 1-MW stall-regulated rotor. Starting point was the new LM-24.0 blade. The cost function was assumed to depend only on fatigue loads. By use of traditional airfoils a possible reduction of 5.5% in the kWh-price was achieved. This was established by a small reduction of the annual production and hence aerodynamic efficiency, that was counterbalanced by a larger reduction in fatigue loads. With parametric airfoil characteristics a further reduction of 6% was found possible. Airfoils matching these requirements have however not yet been developed.

In the initial phase of the 'blade design' project, a 1.5-MW stall regulated rotor was designed. Starting point was two new 1.5-MW prototypes. The aim was to find areas of interest as regards reduction of the kWh-price. In this phase the cost function was phase dependent on both fatigue and extreme loads. In an extensive parameter investigation the following areas of interest were revealed:

- blade optimization in general
- airfoil design
- reduction of extreme loads
- improved allowable fatigue and extreme blade strains.

Blade optimization to existing constraints (eg strains and traditional airfoils) showed a 2.5% reduction of the kWh price. It was found possible to maximize the strain on more than 80% of the blade resulting in reduced blade weight. Optimum parametric airfoil characteristics showed a 5.6% reduction of the kWh price. Optimum airfoils should have a relatively high $C_{\ell(\max)}$ on the entire blade. A reduction of the extreme load cases showed a possible reduction of 9% in the kWh price. The optimization studies did so far concern constant speed stall-regulated rotors. Potential improvements from pitch regulation and variable speed were not investigated.

It appears that a possible reduction of the kWh price is much dependent on existing problems, especially the cost function, the allowable stresses/strains and the degree of detail of the component shapes assumed. The results presented are conservative in all respects, and they were compared to the state-of-the-art of modern wind turbines. Thus larger improvements can be obtained by use of more advanced component modelling and more innovative component shapes/concepts than those used to obtain the results presented. This should however take place in the detailed design phase at the wind turbine manufacturers.

3.2 Atmospheric fluxes over biosystems and interactions with the climate system

Risø has a long tradition for micrometeorological studies, both theoretically and experimentally, relating atmospheric fluxes and mean values to surface characteristics. One of the major applications of the field is the study of fluxes of momentum (surface stress), heat and trace constituents between the atmosphere and the underlying surface. The latter can be downward fluxes of air pollutants of anthropogenic origin or bidirectional fluxes of "natural" compounds such as water vapour, CO_2 and other gases involved in the biological activities of the underlying ecosystems.

Especially water vapour has gained increasing interest in recent years, which is signified through large international programs such as BAHC (Biospheric Aspects of the Hydrological Cycle) and GEWEX (Global Energy and Water Cycle Experiment). This is partly because of recognized large importance of water vapour for

the general dynamics of the atmosphere and partly because of the prospects of scarce resources of water for human consumption.

Together with the two other classical meteorological fluxes, momentum and sensible heat, the water vapour flux is a basic part of all the studies reported below, both because they are of importance in themselves, and because they provide scaling factors for use in connection with all other fluxes estimated and modelled.

Exchange between the atmosphere and terrestrial ecosystems

Fluxes between the atmosphere and terrestrial ecosystems have been studied over three different types of ecosystems:

1. Agricultural crops of opportunity at Risø's own measuring station (RIMI) and in the TRACT/BIATEX projects within the EUROTRAC program
2. Coniferous forest at the Speulderbos in Holland within the EC-FOREXNOX project, led by TNO/The Netherlands, and similarly in a long-term multidisciplinary study at Ulfborg, Denmark, on the so-called forest decline, sponsored by EC, DG-VI
3. Deciduous (beech) forest on a site at Sorø near Risø. This project is sponsored by the EU Environment and Climate program.

The compounds studied in these projects are mainly O_3, NO and NO_2 but in certain cases also NH_3 and HNO_3 (in collaboration with NERI, the National Environmental Research Institute).

Finally the department is involved in a joint project called BEMA dealing with biogenic emissions of volatile organic compounds (VOCs) in a European consortium, which is sponsored by the EC-Environment program.

As concerns exchange of greenhouse gases we participate in the GEFOS project (Greenhouse gas emissions from farmed organic soils) in which we measured emissions of CO_2, CH_4, and N_2O during short campaigns in Sweden using the relaxed eddy-accumulation technique and FTIR spectroscopy (in collaboration with IVL, Göteborg). Here we shall present some results of the exchange of CO_2 from a 80-year old beach forest. The photosynthetic fixation of CO_2 by green plants (terrestrial plants as well as aquatic algae etc.) represents a very large flux. A typical value for terrestrial vegetation (a forest during spring without water shortage) is about 1 $\mathrm{mg\,m^{-2}s^{-1}}$ in the middle of the day. Figure 1 shows an example of the diurnal variation of the total flux (fixation minus respiration) measured over a beech forest in June (the vertical bars represent the day to day variability of the flux). By night a loss of about 0.2 $\mathrm{mg\,m^{-2}s^{-1}}$ is seen. This is owing to the metabolism or respiration of the system.

In winter respiration dominates, and a lot of the fixed carbon is released to the atmosphere. To a large degree this occurs through the action of microorganisms. In the northern temperate latitudes this causes an amplitude in the atmospheric CO_2 content of about 15 ppm compared to a mean level of around 350 ppm. Because of anthropogenic emissions (combustion of fossil fuels) the atmospheric concentration of CO_2 is increasing. The current trend is about 1.25 ppm per year. Thus it will take approximately 12 years for the accumulated input to be larger than the amount cycled annually by the biosphere. The anthropogenic release is about 6 Giga (109) tons per year. If all of the release remained in the atmosphere, the annual concentration increase would be larger than that stated above. However only about half of it remains in the atmosphere. The rest is sequestered by the biosphere. The fraction is actually quite variable. The atmospheric increase can vary from 1 to 5 Giga tons per year. This signifies that the biological processes removing the CO_2 are highly dependent on some variable conditions. A debate at

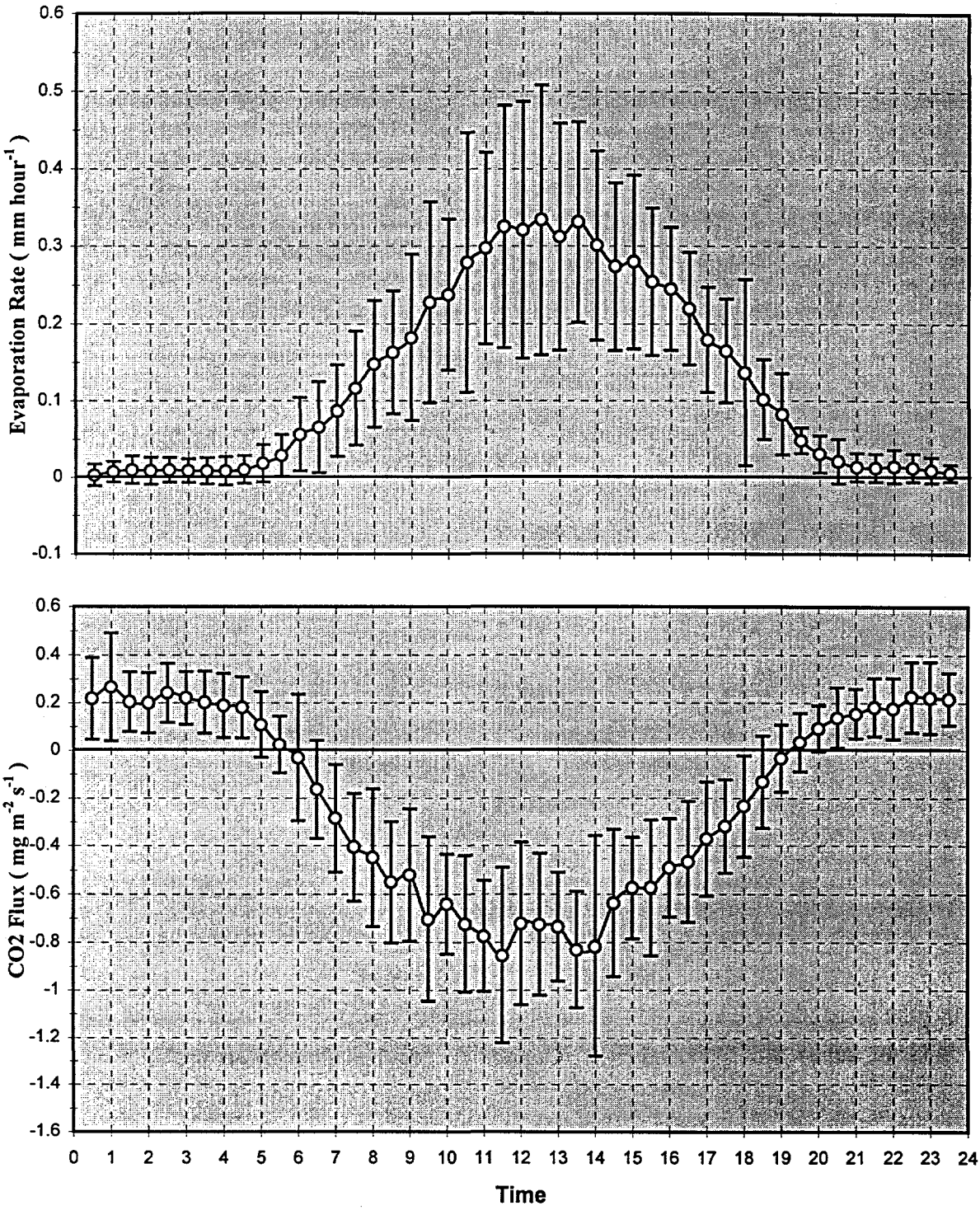

Figure 2. Ensemble mean diurnal variation of the evaporation (upper frame) and the CO_2 exchange over the beech forest at Sorø for June 1996. Vertical bars indicate day by day variations (st.dev.) Positive values indicate fluxes directed upward. Thus the forest has a net uptake of carbon between 05.30 and 19.00 (on the average), but respires carbon by night.

issue is where the CO_2 actually disappears, into the terrestrial biosphere or into the oceans? Current understanding and upscaling of experimental results are not able to quite account for the magnitude of the sink. A number of IGBP (International Geosphere Biosphere Programme) projects are dealing with this question. Risø is an active participant in a number of these projects.

We participate in an international project (supported by EC) which has the objective of performing long-term measurements of the CO_2 flux to a forest ecosystem. It may be a forerunner for a global project with the same objective. A plot of the measurements performed during the first season at our site is presented in fig 2. The total daily amount of net carbon fixation is seen to vary quite a bit; around day 200 to day 210 (mid-July) it changes from a gain of six to a loss of one gramme of carbon per square metre per day. On day 270 (by the end of September) the net fixation ceases and respiration takes over. The ultimate goal is to be able to model the exchange as a function of external parameters such as soil water, atmospheric humidity, solar radiation, temperature etc. Therefore it is necessary also to study the fluxes from the different compartments of the ecosystem (the soil surface which is a respiratory source, the understory, and the canopy as such). So in addition to the micrometeorological measurements, which are done by eddy correlation above the canopy, we also use soil chambers and other additional measurements.

Fluxes between the atmosphere and aquatic ecosystems

Also the study of the exchange between the atmosphere and the sea has a long record at Risø. Originally it was aimed at an understanding of the relation between the surface stress, wave and current fields and spray production for the purpose of improved wave-generation models and interpretation of remote sensing data over the ocean surface. The main sponsors in the first period were NATO (ASI-Panel) and US Office of Naval Research (ONR). From the mid-eighties also the exchange of atmospheric anthropogenic pollutants and the sea became an important objective of the research. The Danish Marine Research 90 Programme focused primarily on the eutrophication of the inner Danish waters because of excess nutrient supply, and the EC-ENVIRONMENT Programme focused on the characteristics of a polluted marine atmospheric boundary layer. In this period much of the research was conducted within the EUROTRAC Air-Sea Exchange subprogram. The overall main result of these studies was that deposition of nitrogen compounds to the seas was found to be one of the main, at times the most important, source of new nutrients to coastal seas, not only in Denmark but in most or all areas where studies had been conducted.

Currently the research continues to aim at the physical coupling processes between the ocean and the atmosphere with the general objective of improving our understanding of the marine boundary layers, and specifically to improve shallow-water hydrographic models. Last but of great importance was the wish to erect offshore wind farms. The latter have raised the demand for improved insight into the wind climate of coastal offshore areas, necessitating improved description of the surface roughness and the thermal forcing in these very complicated regions. Main sponsors within these subjects have been Danish wind-energy programs, the Danish Utilities, EC-JOULE, Danish Technological Research Council and ONR. The latter has continued its support throughout the years.

Simultaneously the research in air-sea exchange of constituents has continued and has also increased. Many of the nutrient fluxes, estimated earlier, have shown up to be regulated by more complicated processes than originally considered, while the concern about global issues, such as climate variability, has led to increased research on the air-sea exchange of greenhouse gases. The main sponsors of these

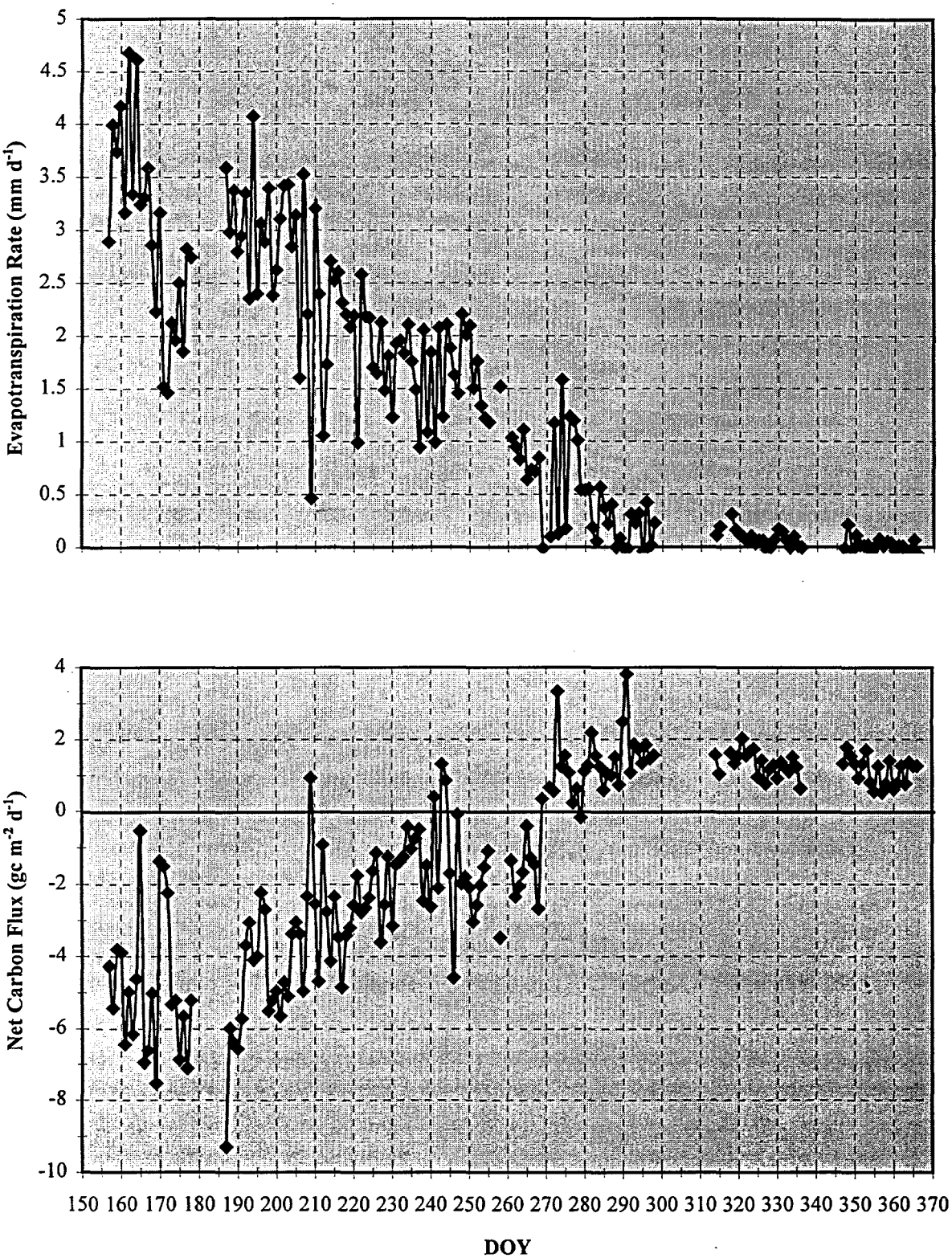

Figure 3. Seasonal variation of daily integrated exchange of water vapour (upper frame) and carbon from the beginning of the EUROFLUX measurements over the beech forest at Sorø until the end of 1996. The net respiration is seen to take over at around day 270 (approximately 1 October). The measurements will continue for a number of years (DOY means day of year).

studies have by far been EC-ENVIRONMENT and MAST, but also ONR and the Council of Nordic Ministers have supported this research.

The renewed studies of fluxes of nitrogen compounds across the air-water interface have focused on the role of chemical reactions including reactions between the gases and marine aerosols. For gases with a high affinity to water such as HNO_3 and NH_3, parametrization of these processes needs to be included in models for dry deposition. It was found that the importance of gas-aerosol reactions depends on the production of marine spray particles as well as on the chemical dis-equilibrium between the particles and the air concentration of the gases under consideration. For a gas like ammonia also the water concentration was found to be significant, at times resulting in an upward flux of ammonia dependent on the state of the biology in the water. The first experiments on these subject were performed on the site of the first Danish wind farm, Vindeby, where in recent years Risø has conducted many of its coastal air-sea interaction studies. They have presently been moved to a site close to Gotland in the Baltic Sea, both to coordinate the measurements with recent EC programs, BASYS, and to obtain data from deeper waters than is possible on the Vindeby site. The main gases with climate impact are the so-called greenhouse gases that influence the radiation balance of the globe. Here the most well-known is CO_2, where the oceans are sinks, and CH_4 and N_2O, where the ocean are considered sources. However also other constituents are of importance such as the sea salt particles and volatile sulphur compounds, both species being important sources of cloud condensation nuclei. To some extent all of the global budgets for these constituents are problematic in the sense that presently they cannot be closed satisfactorily.

For the gases the ocean concentrations are highly variable in space and time, so a main challenge is to map the concentration variations. Another challenge is however to improve the understanding of the processes responsible for the air-sea exchange of the gases. To some extent they are all very slowly dissoluble gases, meaning that the water surface exerts a high resistance against transfer. The semi-empirical relations derived are all somewhat in doubt and not sufficiently general to allow for flux estimates under general conditions and to transfer data from one set of conditions to another in a simple and reliable way, such as fresh water/salt water, clean water/contaminated water, horizontally homogeneous/inhomogeneous water concentrations etc. Risø has participated in projects on improved estimation of the exchange rates for such gases, mostly sponsored by EC MAST and ENVIRONMENT. In a laboratory study in the air/sea exchange tunnel in Marseille (the EC-LUMINY experiment) studies are presently being conducted on the exchange rate for such gases for different wave-modulation and spray and bubble production rates. (The waves modulate the thickness of the interfacial layer, or disrupt it when the waves are breaking, while the bubble and spray always disrupt the layer, when the bubbles burst to produce spray). Simultaneously a field measuring program for the same gases is being conducted from the Dutch scientific platform MeetPoost Nordweijk in the North Sea (the EC-ASGAMAGE project). Here we focus especially on measuring the CO_2 flux by micrometeorological methods in relation to the difference in partial pressure of CO_2 in water and air.

Finally Risø participates in the mapping of fluxes of CO_2 across the marginal seas of Western Europe in an effort to estimate if those seas contribute negatively or positively to the atmospheric CO_2 budget (the EC-OMEX project). In this project Risø again focuses on determining the fluxes by micrometeorological methods, in this case the eddy-cospectral and dissipation methods as well as by the exchange coefficient method, relying on measurements of difference in water and air concentrations. In these projects we have for the first time found the methods mentioned above to yield comparable results over the sea, both from platforms

and from a moving ship.

The OMEX (Ocean Margin EXchange) project focuses on the carbon balance of the entire water column from the sediments to the atmosphere, since the main aspect of the CO_2 budget in relation to climate is the balance between atmospheric CO_2 and the CO_2 deposition into the marine sediments, that presently is the only final depository we can imagine for CO_2. Aside from air-sea exchange this deposition process involves marine biology and chemistry as well import/export across the shelf break as being decisive for a final deposition of the CO_2 to the sediment or whether it remains in the water column in balance with the atmosphere and responding to the cycle of the marine life. Figure 3 depicts the undersaturation of CO_2 in water as measured during one of our OMEX cruises. Clearly indicated is the undersaturation at high latitudes (cold) and supersaturation at low latitudes (warm).

To a large extent the Risø work described above has involved intensive cooperation with other institutions both Danish and foreign. In recent work the most important Danish partners have been Danish Hydraulic Institute concerning the physical air-sea interaction, and Danish Environmental Research Institute on the subject of air-sea exchange of gases and particles. Of foreign institutions the most important partner has by far been TNO (Dutch), that has participated in almost all of the exchange work cited above. Together with TNO Risø has often formed joint teams for much of the experimental activity, sharing instrumentation and work load, each covering their part of the necessary knowledge.

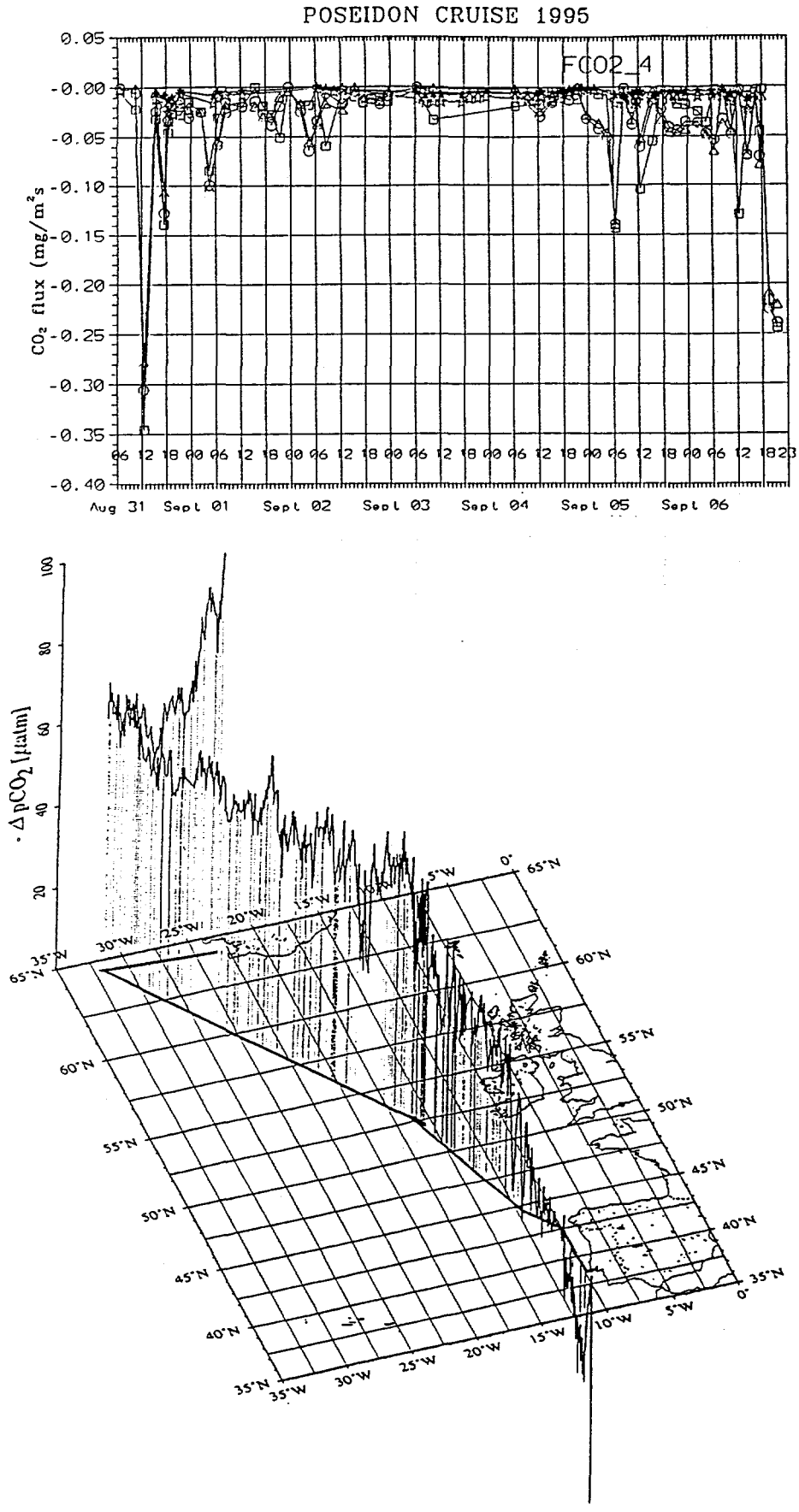

Figure 4. CO_2 fluxes and undersaturation along a cruise trajectory, Poseidon 211, September 1995 from Iceland to Portugal. Undersaturation and geochemical fluxes (white and black stars) made by Keir et al, GEOMAR. Also shown are the micrometeorological fluxes made by the Risø team (□, △, ○).

4 Dissemination and Utilization of Research Results

4.1 Wind energy R&D indicators

In 1996 the budgets for wind energy research, development and demonstration within the OECD countries amounted to approximately 175 Millions USD (anticipating an exchange rate of 1 USD to 5.55 DKK)[1]. A part of this is market support to demonstration activities. It is estimated that the R&D activities account for 100 to 150 M USD on an annual basis for the period 1995 - 1996. The department's 1996 turnover (budget) in wind energy was 43.8 M DKK or 7.9 M USD (with the above-mentioned exchange rate) including commercial activities. From this it can be estimated that Risø accounts for approximately 5% of the (OECD) world's wind energy research and development. It means that Risø is the largest wind energy research institution throughout Europe, ie of the same size as NREL (American). Still Risø's wind energy activities account only for 1,1% of the 4000 M DKK turnover of the Danish wind energy industry. In Denmark – as in most countries – most resources of the governmental wind energy R&D programs are granted to either industrial enterprises or to dedicated wind energy research organizations (like Risø in Denmark). World-wide only a very limited university-based "free or basic research" is carried out within wind energy. As dedicated wind energy research organizations Risø's major "sister organizations" are: NREL, Golden, Colorado, USA; DEWI, Wilhelmshaven, Germany; ECN, Petten, The Netherlands; NEL, East Kilbride, Scotland, UK; CIEMAT, Madrid, Spain; CRES, Pikermi, Greece.

Clients

Successful utilization of our research is of paramount importance to the department. Our clients and users of our research fall into three categories (listed in order of importance):

- Industry
  - wind power industry
  - power utilities and their organizations
- Authorities
  - national (eg Danish Energy Agency, DANIDA),
  - European (EU CEC)
  - international (IEA, UNDP, World Bank)
- Scientific communities
  - project partners within universities and laboratories
  - Ph.D. students

Channels of interaction and dissemination

We make use of a number of channels when interacting with our clients:

- direct dialogue at theme conferences etc.
- direct co-operation on R&D projects within Danish and European R&D programs

[1] IEA Wind Energy Annual Report 95

- international conferences
- international standardization
- research based type-approval activity
- research based turbine and blade testing activity
- publications
  - informal, but fast (telefax) information to industry
  - research reports (both public and internal/confidential)
  - codes, standards and guidelines
  - conference papers
  - papers in peer-reviewed journals

Direct dialogue with the wind-energy industry

Direct dialogue. Prior to the 1996 round of submitting proposals to the Danish Energy Research Programme '97, three key senior scientists visited five Danish wind turbine companies attended by the director of The Danish Wind Turbine Manufacturers' Association in order to discuss future research projects and possibilities for co-operation. The team had discussions with the chief executives of the companies in question and heads of their R&D departments.

Risø Wind Energy Day '96 was held on 14 August with approximately 100 participants. On that occasion a broad range of Risø's wind energy activities were presented for an invited audience among our key clients.

Theme conferences. In 1996 four theme conferences were held with focus on dissemination and dialogue with the R&D departments of the industry and utilities:

- 13 March - Grid Integration of Wind Turbines
- 30 May - Wind-Turbine Technological Research Projects
- 14 August - Overview of Aerodynamics Research under the Danish Energy Research Programme, held by the end of Risø Wind Energy Day.
- 30 October - Multi-Pole Generators for Wind Turbines.

Patents

Until now the department has not made use of patents as a tool for dissemination. Because of the wind-turbine technological characteristics our knowledge is protected through other mechanisms. A survey of the patent statistics from 1970 -1992 revealed that the Danish wind industry (with a 50% world market share) only had 15 patents out of a total of 5081 patents in the leading wind energy countries throughout the world. Only one or two of these 15 patents were actually used. We estimate that in the future patents will play a more important role within the industry, but necessarily not as a dissemination tool.

4.2 International Publication

A search in the IEA Energy Date Base indicates how Risø's wind energy publication activities compares with those of our sister organizations, see figure 3. The publication activity roughly reflects the size, budget and age of the organizations mentioned – especially no 1–4. This indicates that our publication activity is on the same level as that of our major sister organizations.

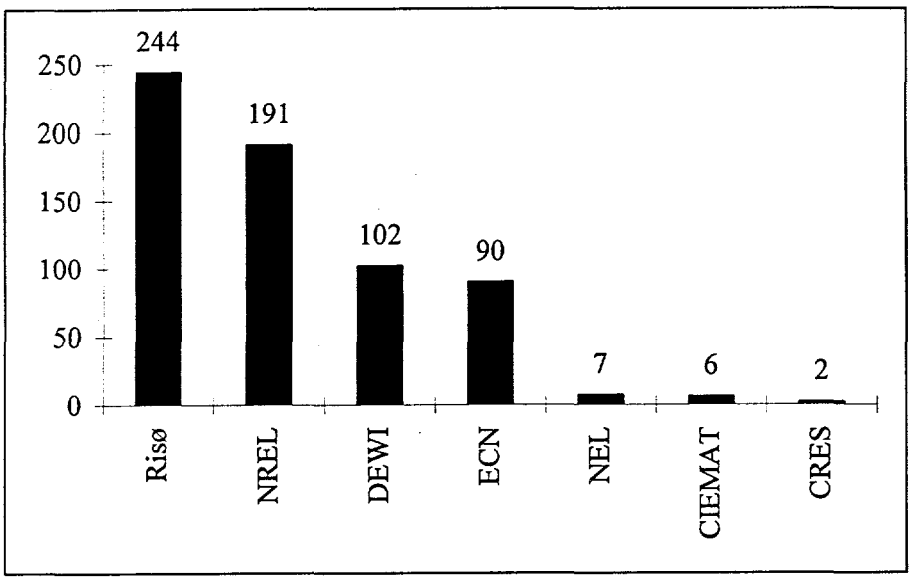

Figure 5. Number of wind energy references for Risø and its major sister organizations. Source: IEA-Energy Technology Data Exchange (ETDE) Energy data base on all wind energy references, all years.

In countries with active wind energy R&D programs the quality and relevance of the activities are secured through: 1) industry participation in defining the relevant areas and goals, and 2) through comprehensive examination of proposals submitted. This is also the case for the Danish Energy Research Programme (EFP) and the EU Joule program; two of the largest financial sources for Risø's wind energy research. These programs emphasize strong industry participation and industry-oriented dissemination in the projects, and in general publications in peer-reviewed journals has a low priority. A search in the IEA-Energy Technology Data Exchange (ETDE) Energy data base on all references published in the period 1990 – 1997 shows that the most common types of publication are reports, conference proceedings or conference papers, see figure 4. Of the 4058 reports, journal articles and books mentioned a number of 1726 were conference proceedings or conference papers.

Table 1. Distribution of references in IEA-Energy Technology Data Exchange (ETDE) Energy Data Base on all wind-energy references published in the period 1990–1997.

Type of publication	Number	
Report	2018	of these publications
Journal	1214	a number of 1726 were
Book	826	conference proceedings
Patent	137	or conference papers

International Conferences

In general wind energy conferences has a strong industry presence. The largest ones are an annual European conference (sponsored by the European Union and/or European Wind Energy Association) and two annual American conferences (one sponsored by American Wind Energy Association and the other by American Society of Mechanical Engineers). It is a tradition that presentations also take place at the annual conference of the British Wind Energy Association.

The 1994 European Wind Energy Association Conference held in Thessaloniki had a participation of approximately 500 persons from 38 countries. Our department presented (as authors or co-authors) 21 papers out of the total number of 165 papers presented. Of these 14 papers (out of 92) were selected for oral presentation, the remainder as poster presentations. Of the department's 21 papers two papers had co-authors from other Danish organizations, and five papers had foreign co-authors.

A number of 120 persons participated in the small 1995 European Wind Energy Association Special Topic Conference on economic issues held in Helsinki. The Department presented (as authors or co-authors) three papers out of a total number 33 oral presentations. Two presentations involved co-authors from other Danish organizations and one presentation involved a foreign co-author.

The 1996 European Union Wind Energy Conference in Göteborg was attended by approximately 600 persons. The department presented (as authors or co-authors) 32 papers of a total number of 280 papers presented. Of these, 17 out of 124 papers were selected for oral presentation, the remainder as poster presentations. There were four invited key-note presentations two of which involved participation from the department (one was presented by the department, and one with participation from the department). Three out of the total number of 32 papers from our department involved Danish co-authors, and ll papers involved foreign co-authors.

The department regularly present papers at the two American conferences, but at a much lower level of participation (one or three presentations at each conference) because of the travelling expenses.

4.3 Programme participation

Programme participation is the most significant contribution to the our R&D effort.

On a national level Risø is primarily participating in the Danish Energy Research Programme (EFP) but is participating also in the Danish Development Programme for Renewable Energy (UVE). The total financial frame of these programs (especially as regards the research part) is increasing.

In the EFP-96 round industry and utility-headed projects (but with Risø participation) and a power-utility-headed offshore project (without Risø participation) were preferred. In the EFP-97 round only Risø (department) headed projects obtained support. For most contracts part of the funding goes through Risø to subcontractors and consultants.

On a European level we submit proposals and obtain contracts under several programs including JOULE, THERMIE, ALTENER and APAS.

Under the EU Fourth Frame Programme in 1995 (the Joule part) we were involved in 29 proposals (as coordinator in 11 and as a partner or consultant in 18 proposals). Fourteen of these projects gained support from the EU. An overall rate of success of 50% is an exceptionally fine result.

The total Risø budget for these projects are 3.14 MECU, with a 50% support from EU. This equals 8.4% of the total JOULE wind energy budget of 18.6 MECU.

On an international level (beyond EU) no available research funding exists. International co-operation is coordinated through the IEA wind energy R&D agreement, but funded through national programs. In 1996 we participated in a Round Robin test of an American wind turbine. The test was organized by IEA. The department also participated in several workshop and expert meetings arranged under the IEA Wind Energy R&D Agreement.

4.4 International standardization

Since 1982 we have emphasized participation in Danish and international standardization. These activities have been funded by the Danish Energy Agency. Especially since 1988 our standardization effort has been oriented towards the international community with participation in technical committees and working groups under IEC (international) and CENELEC (European). The aims of our standardization effort are to

- secure the wind-turbine quality through mutually accepted technical requirements
- disseminate results from our research to be used directly in the technical requirements in question
- contribute to a simple and international standardization facilitating free international trade
- support the Danish technical criteria of type approval and certification of wind turbines.

The Danish effort is coordinated by the Danish National Committee S-588 under Dansk Standard. Peter Hauge Madsen, deputy head of the department, is chairman of S-588.

CENELEC and CFN, its sister organization, carry out standardization on a European level. Wind turbine issues are handled by the CENELEC Technical Board Task Force 83-2 (BTTF 83-2). C. J. Christensen, senior scientist in the department, is appointed chairman of BTTF 83-2). Risø is participating also in two of the three active working groups, see table 2.

Table 2. Overview of working groups under the CENELEC Technical Board Task Force 83-2 (BTTF 83-2), indicating the department's involvement.

WG	Topic	Status	Risø participation
1	engineering integrity		1 member
2	electrotechnical issues		
3	labour safety		1 member
(4)	acoustic noise (being established)		

The work in CENELEC receives no direct funding from the European Commission or any national agencies. Only expenses to chairmen and secretaries are covered. Therefore most scientific work involved in the standardization is funded by the European Commission within the framework of the Joule program European Wind Turbine Standards I + II (EWTS I + II). The research and development work on future CENELEC standardization is carried out by seven working

groups. The department participates with one or more persons in all seven groups, see table 3.

In 1987 the International Electrotechnical Committee (IEC) decided to establish Technical Committee no 88 Safety of Wind Turbine Generator Systems. C. J. Christensen, senior scientist in the department, was appointed (and has since served) as chairman of this IEC TC88. A number of working groups have been established, and some have finalized their tasks. Employees from the department are participating in five of the seven active working groups and convene three groups, see table 4.

Table 3. Overview of working groups under European Wind Turbine Standards II (funded by EU), indicating the department's involvement.

WG	Topic	Status	Risø participation
1	load spectra	active	3 persons
2	qualification of load spectra	active	2 persons
3	integration of blade tests in design	active	1 person
4	power performance in complex terrain	active	2 persons
5	site evaluation techniques	active	2 persons
6	setup of MEASNET	active	2 persons
7	general task	active	2 persons

Table 4. Overview of working groups under the International Electrotechnical Committee (IEC), Technical Committee no 88 Safety of Wind Turbine Generator Systems, indicating the department's involvement.

WG	Topic	Status	Risø participation
	International Electrotechnical Vocabulary - Chapter 415: Wind turbine systems	finalized	–
1	philosophy	finalized	–
2	engineering integrity	finalized	–
3	installation, maintenance and operation	finalized	–
4	safety of small wind turbines	finalized	–
5	acoustic noise measurement techniques	active	–
6	power performance measurement techniques	active	convenor + 1 member
7	revision of part 1: safety requirements	active	convenor + 2 members
8	testing methods for rotor blades (guideline)	active	1 member
9	certification procedures of wind turbines	active	1 member
10	power quality requirements	active	convenor
11	mechanical load measurements	active	1 member

5 Committee and expert group memberships

Christensen, C.J. *Chairman*, International Electrotechnical Committee, Technical Committee 88, Wind Turbine Systems.

Christensen, C.J. Dansk Elektroteknisk Komité, DEK. Teknisk Udvalg 88 (TU88) Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems).

Christensen, C.J. International Electrotechnical Committee (IEC). Technical Committee 88 (TU88) Safety of Wind Turbine Generator Systems, Working Group 17.

Christensen, C.J. *Chairman*, European Standards for Wind Turbines, CENELEC BTTF 83-2.

Dannemand Andersen, P. Danish Energy Agency, Coordination Group on Wind Energy.

Dannemand Andersen, P. Danish Energy Agency, Technical Committee on Certification and Type Approval.

Dannemand Andersen, P. Danish Energy Agency, Advisory Committee on Certification and Type Approval.

Frandsen, S. Steering Committee for Egyptian-Danish Collaboration Project on Wind Energy.

Frandsen, S. Dansk Elektroteknisk Komité, DEK. Teknisk Udvalg 88 (TU88) Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems).

Frandsen, S. International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 6 on Test Procedures for Wind Turbine Testing.

Gryning, S.E. *Deputy Chairman*, Danish Meteorological Society (DAMS).

Gryning, S.E. *Honourable Secretary*, European Association for the Science of Air Pollution (EURASAP).

Gryning, S.E. *Chairman*, Executive Committee, NOPEX.

Gryning, S.E. International Scientific Committee on Operational Short-Range Atmosphere Dispersion Models for Environmental Impact Studies, Workshop Series.

Gryning, S.E. *Chairman*, Scientific Steering Committee on International Technical Meetings on Air Pollution Modelling and Its Application, Conference Series.

Gryning, S.E. COST Action 710. Processing of Meteorological Data for Dispersion Modelling. Working Group 2: Mixing-Layer Depth Determination for Dispersion Modelling..

Gryning, S.E. Science Panel on Atmospheric Chemistry Research (EU DG XII).

Gryning, S.E. International Scientific Committee on the ETEX (European Tracer Experiment) Symposium, Viennea, May 1997.

Gryning, S.E. International Scientific Committee on the Stable Boundary Layer Workshop, Sweden, October 1997.

Gryning, S.E. *Chairman*, EUROSAP Workshop on Mixed Layer Height, Risø National Laboratory, 1–3 October 1997.

Gryning, S.E. *Guest Editor*, Atmospheric Environment, Special Issue of the MEDCAPHOT Trace Experiment.

Harvøe, P. Danish Energy Agency. Technical Committee for Small Wind Turbines.

Harvøe, P. Danish Energy Agency, Promotor Committee for Small Wind Turbines.

Harvøe, P. Tønder Technical School, Educational Wind Farm.

Hasager, C.B. DANMAC, Danish Multisensor Airborne Campaign.

Hummelshøj. P. *Secretary*, Nordic Society for Aerosol Research (NOSA).

Højholdt, P. Danish Energy Council, Promotor Committee for Small Wind Turbines.

Højholdt, P. Technical Committee for domestic wind turbines.

Jensen, N.O. European Geophysical Union, *Secretary*, Meteorology, under Oceans and Amosphere (OA).

Jensen, N.O. *Secretary*, Steering Committee, Danish Centre for Atmospheric Research (DCAR).

Jensen, N.O. *Management Board*, Center of Air Pollution Processes and Models under the Danish Environmental Research Programme 1992–1996.

Jensen, N.O. *Management Board*, Center of Atmosphere Related Ecosystem Research under the Danish Environmental Research Programme 1992–1996.

Jensen, N.O. National Committee on IUTAM. International Union of Theoretical and Applied Mechanics.

Jensen, N.O. National Committee for the International Geosphere-Biosphere Programme (IGBP).

Jensen, N.O. *Editorial Board*, Boundary-Layer Meteorology.

Jensen, N.O. *Chairman*, Boundary Layer Dynamics and Air-Sea Interaction, Working Group A, under ICDM/IAMAS (International Commission on Dynamic Meteorology/International Association of Meteorology and Atmospheric Physics).

Jensen, N.O. *Secretary*, International Commission of Dynamic Meteorology (ICDM).

Jensen, N.O. *Associate Editor*, Quarterly Journal Royal Meteorological Society.

Jensen, P.H. International Electrotechnical Committee, Technical Committee 88, Wind Turbine Systems.

Jensen, P.H. Dansk Elektroteknisk Komité, DEK. Teknisk Udvalg 88 (TU88) Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems).

Jensen, P.H. *Secretary*, Danish Energy Agency Committee on Criteria for Design and Certification of Wind Turbines, Working Group 17.

Jensen, P.H., *Convener*, International Electrotechnical Committee (IEC). Technical Committee 88 (TC88) Safety of Wind Turbine Generator Systems.

Jensen, P.H., *Secretary* European Wind Energy Association (EWEA), Corporate Group.

Jensen, P.H. Danish Energy Agency, Wind Energy Advisory Committee.

Jensen, P.H. European Standards for Wind Turbines, CENELEC BTTF 83-2.

Jensen, P.H. Danish Energy Agency, Wind Energy Research Committee (DK).

Kristensen, L. *Associate Editor*, Quarterly Journal Royal Meteorological Society.

Krogsgaard, J. *Governing board*, European Small Hydro Power Association (ESHA).

Krogsgaard, J. *Editorial Committee*, European Small Hydro Power Association (ESHA). Atlas of European Small-Scale Hydro Potential.

Krogsgaard, J. *Editorial Committee*, European Small Hydro Power Association (ESHA). Layman's Guidebook on how to develop a small hydro site.

Krogsgaard, J. *Editorial Committee*, JWB study on hydro power.

Larsen, S.E. National Committee for the International Geosphere-Biosphere Programme (IGBP).

Larsen, S.E. The Coordinating Committee on the Marine Aerosol and Gas Exchange Project of the International Global Atmospheric Chemistry Program.

Larsen, S.E. The National Committee for Climate Research. The Danish Committee under the World Climate Programme.

Larsen, S.E. Steering Committee of the OMEX (Ocean Margin Exchange) Programme.

Larsen, S.E. *Coordinator*, Steering Committee of the OMEX CCB (Carbon Cycle and Biogases) Project.

Larsen, S.E. Influence of Sea State on the Atmospheric Drag Coefficient, SCOR (Scientific Committee on Ocean Research), Working Group 101.

Madsen, P.H.*Chairman*, Dansk Standard (DS). Teknisk Udvalg S588, Sikkerhed af Elproducerende Vindmøller (Danish Standard, Technical Committee S588, Safety of Wind Turbine Generator Systems).

Madsen, P.H. *Chairman*, International Electrotechnical Committee (IEC). Technical Committee 88 (TC88), Safety of Wind Turbine Generator Systems, Working Group 7, Revision of Part 1: Safety Requirements.

Madsen, P.H. *Chairman*, International Electrotechnical Committee (IEC). Technical Committee 88 (TC88), Safety of Wind Turbine Generator Systems, Working Group 9, Certification Procedures of Wind Turbines.

Madsen, P.H. European Standards for Wind Turbines, CENELEC BTTF 83-2.

Madsen, P.H.*Member of the Board*, Fuel and Combustion Technology Association, Danish Society of Chemical, Civil, Electrical and Mechanical Engineering (IDA).

Mikkelsen, T. European Expert on Selection of Atmospheric Dispersion Models for Real-Time Decision Support, DG-XII.

Mikkelsen, T. Member of RODOS Project Management Group (RMG). DG XII Radiation Protection Research.

Mortensen, N.G. Nordic TEX Committee.

Mortensen, N.G. Quality Control Committee on Exhibition on Energy Production and Environment.

Mortensen, N.G. Corps of External Examiners, University of Copenhagen.

Pedersen, T.F. Dansk Elektroteknisk Komité, DEK. Teknisk Udvalg 88 (TU88) Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems).

Pedersen, T.F. *Chairman*, International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 6 on Test Procedures for Wind Turbine Testing.

Pedersen, T.F. Danish Energy Agency, Technical Committee on Certification and Type Approval.

Pedersen, T.F. *Convenor*, International Electrotechnical Committee (IEC), Technical Committee 88 (TC88) Power Performance Measurement Procedures.

Petersen, E.L. EUREC-Agency EEIG.

Petersen, E.L. *Editorial Board*, International Journal of Solar Energy.

Petersen, E.L. *Chairman*, 1999 European Union Wind Energy Conference and Exhibition, Nice, France.

Skamris, C. International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 9.

Skamris, C. Danish Energy Agency, Technical Committee on Certification and Type Approval.

Tande, J.O. *Chairman*, International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 10.

Thykier-Nielsen, S. Ad Hoc Group on the NEA/CEC Intercomparison Exercise on PCA Codes.

Winther-Jensen, M. Advisory Committee on Insurance, the Danish Wind Power Utilities.

Winther-Jensen, M. Transmission Technical Advisory Committee (GIG).

Winther-Jensen, M. International Electrotechnical Committee (IEC). Technical Committee 88 (TC88), Working Group 8 on Testing of Rotor Blades.

Winther-Jensen, M European Standards for Wind Turbines, CENELEC BTTF 83-2.

6 Staff and Guests

6.1 Administration

Scientific staff

Petersen, Erik Lundtang, Department Head
Madsen, Peter Hauge, Deputy Head

Secretaries

Christiansen, Ulla Riis
Viktorius, Gitte

6.2 Meteorology

Scientific staff

Astrup, Poul
Courtney, Michael
Frank, Helmut
Gryning, Sven-Erik
Hummelshøj, Poul
Højstrup, Jørgen
Jensen, Niels Otto
Jørgensen, Hans E.
Kristensen, Leif
Landberg, Lars
Larsen, Søren E., Programme Head
Mann, Jakob
Mikkelsen, Torben
Mortensen, Niels Gylling
Rathmann, Ole (from 1 May)
Nielsen, Morten
Sanderhoff, Peter
Thykier-Nielsen, Søren

PhD. students and Post.docs

Brandt, Jørgen
Geernaert, Lise Lotte Sørensen
Hasager, Charlotte Bay
Kjeld, Jørgen Friis
Jensen, Anne Katrine Vinter
Sempreviva, Anna Maria
Vignati, Elisabetta

Technical staff

Christensen, Lars
Hansen, Arent
Hansen, Finn
Hansen, John
Jensen, Gunnar
Lund, Søren W.
Nielsen, Jan

Secretary

Skrumsager, Birthe

6.3 The Test Station for Wind Turbines

Scientific staff

Andersen, Per Dannemand
Antoniou, Ioannis
Bindner, Henrik, W.
Christensen, Carl Jørgen
Christensen, Henrik (till 30 November)
Fabian, Ole (till 30 April)
Frandsen, Sten
Fuglsang, Peter
Hansen, (Jens) Carsten
Harvøe, Per
Jensen, Peter Hjuler, Programme Head
Kretz, Allan (till 31 October)
Krogsgaard, Jørgen Chr.
Larsen, Gunner Chr.
Lind, Søren
Madsen, Helge Aagaard
Nørgård, Per
Paulsen, Uwe Schmidt
Pedersen, Troels Friis
Petersen, Jørgen Thirstrup
Petersen, Søren Markkilde
Rasmussen, Flemming
Sørensen, Niels
Sørensen, Poul
Tande, John O.
Thomsen, Kenneth
Vølund, Per
Winther-Jensen, Martin

PhD. students and Post.docs.

Dahl, Christian Skriver
Johansen, Jeppe
Søndergaard, Lars

Consultant

Grove-Nielsen, Erik (Sparkær-Centret)

Technical staff

Christensen, Kurt
Hagensen, Flemming
Hansen, Stener
Høst, Oluf
Larsen, Gert
Lund-Thomsen, Hans (Sparkær-Centret)
Nielsen, Finn Linke
Rasmussen, Michael

Secretaries

Andersen, Mette Kuhlmann (temporary employment)
Henriksen, Mette Porsdal
Madsen, Jytte
Westermann, Kirsten

6.4 Approval Office for Wind Turbines

Scientific staff
Højholdt, Poul
Jørgensen, Erik
Koch, Carsten W.
Skamris, Carsten, Head
Technical staff
Lange, Rolf
Secretary
Hansen, Anne Marie

6.5 PhD theses

6.6 Guest scientists

Augi, Rodrigo C.	6 Jun – 6 Aug	Istituto di Fisica Dell'Atmosfera, Rome, Italy
Barthelmie, Rebecca	21 Apr – 31 May	University of Indiana, USA
Barthelmie, Rebecca	1 Jul – 31 Aug	University of Indiana, USA
Batchvarova, Ekaterina	25 Jan – 25 Feb	National Inst. of Meteorology and Hydrology, Sofia, Bulgaria
Batchvarova, Ekaterina	15 Apr – 30 Nov	National Inst. of Meteorology and Hydrology, Sofia, Bulgaria
Beyrich, Frank	15 Apr – 5 Oct	Brandenburg Techn. Univ., Cottbus, Germany
Bowen, A.J.	1 Jan – 14 Jun	University of Canterbury, Christchurch, New Zealand
Chen, Zhong	1 Jul – 31 Dec	University of Beijing, China
Deme, Sándor	28 Apr – 18 May	KFKI Atomic Energy Res. Inst., Budapest, Hungary
Deme, Sándor	14 Oct – 19 Oct	KFKI Atomic Energy Res. Inst., Budapest, Hungary
Ekaterinaris, John	Oct 95 – Oct 96	USA
Fisichella, Chris	28 May – 28 Aug	University of Illinois, USA
Flori, Jean Paul	17 Jun – 29 Jun	Centre Scientifique et Technique du Batiment, Nantex, France
Frank, Helmut	1 Jan – 31 Dec	University of Karlsruhe, Germany
Giebel, Gregor	10 Aug – 31 Dec	University of Oldenburg, Germany
Goodwill, Gilbert	12 May – 6 Jun	Kamada Science & Design, Monterey, CA, USA
Grachev, Andrey	17 Apr – 12 May	Russian Academy of Science, Moscow, Russia
Grachev, Andrey	3 Jun – 10 Jul	Russian Academy of Science, Moscow, Russia
Grigori, Dmitriev	3 Jul – 2 Aug	Apatity, Murmansk, Russia
Gultureanu, Dan	1 Apr – 30 Jun	University of Ploiesti, Romania
Heathfield, Duncan	17 Jun – 29 Jun	University of Edinburgh, Scotland
Kamada, Ray	12 May – 1 Jun	Kamada Science & Design, Monterey, CA, USA
Lavagnini, Alfredo	6 Jun – 20 Jun	Istituto di Fisica Dell'Atmosfera, Rome, Italy
Lenschow, Don	2 Mar – 28 Mar	NCAR, Boulder, CO, USA
Manchiu, Felicia-Speranta	4 May – 3 Jun	IFIN, Bucharest, Romania
Naneris, Christos	10 Jun – 10 Aug	Thessaloniki, Greece
Oncley, Steve	19 Feb – 14 Jun	NCAR, Boulder, CO, USA
Parnis, Paul	1 Sep – 31 Dec	Australia
Pryor, Sara	10 Jul – 29 Aug	Indiana University, Bloomington, USA
di Sabatino, Silvana	1 Feb – 31 Mar	FISBAT, Bologna, Italy
di Sabatino, Silvana	24 Oct – 23 Dec	FISBAT, Bologna, Italy
Santabàrbara Moreno, Josep	15 Aug – 31 Oct	University of Barcelona, Spain
Starkov, Alexander	18 Jul – 2 Aug	RDIEE, Istra, Moscow, Russia

6.7 Short-term visitors (one week or less)

van Boxel, John	6 Nov – 9 Nov	University of Amsterdam, The Netherlands
Cherry, Neil	9 Aug	Lincoln University, New Zealand
Johansen, Per Erik	3 Mar – 9 Mar	FAA, Umeå, Sweden
Johansen, Per Erik	10 Jun – 14 Jun	FAA, Umeå, Sweden
Kunz, Gerard, The Netherlands	9 Dec – 16 Dec	TNO, The Netherlands
Mahrt, Larry	25 May – 2 Jun	Oregon State University, Corvallis, OR, USA
Marigi, Samwel	6 Nov – 9 Nov	University of Amsterdam, The Netherlands
Nikolaev, Vladimir	27 May –28 May	TSAGI, Moscow, Russia
Pécseli, Hans	28 Jan – 4 Feb	University of Oslo, Norway
Pécseli, Hans	10 Aug – 18 Aug	University of Oslo, Norway
Santabàrbara Moreno, Josep	4 Feb – 10 Feb	University of Barcelona, Spain
Selvam, R. Panneer	4 Jul	University of Arkansas, USA
Sun, Jielun	25 May – 30 May	NCAR, Boulder, CO, USA
Tsinober, Arkady	4 Oct	Tel Aviv University, Tel Aviv, Israel
Weber, Harald	26 Aug – 31 Aug	German Military Geophys. Office Traben-Trarbach, Germany
Zilitinkevich, Sergei	19 Feb – 20 Feb	Alfred-Wegener Institute, Bremerhaven, Germany
Zilitinkevich, Sergei	19 Jun – 20 Jun	Alfred-Wegener Institute, Bremerhaven, Germany

7 Publications

7.1 Articles in international periodicals, reports and books

Asman, W.A.H and S.E. Larsen (1996). Atmospheric processes. In: Eutrophication in Coastal Marine Ecosystems. B.B. Jørgensen and K. Richardson (eds), American Geophysical Union, Washington D.C. *Eutrophication in Coastal and Estuarine Studies*, **52**, 21–50.

Barthelmie, R.J., B. Grisogono, and S.C. Pryor (1996). Observations and simulations of diurnal cycles of near-surface wind speeds over land and sea. *J. Geophys. Res.*, **101**, 21327–21337.

Barthelmie, R.J. and N.O. Jensen (1996). Comparison of surface meteorological measurements in TRACT database 4. *Ann. Geophys.*, **14**, 574–583.

Bastrup-Birk, A., J. Brandt and L. Mortensen (1996). Critical levels of O_3 for biomass production of European beech (Fagus sylvatica L). In: Critical Levels for Ozone. Experiments with Crops, Wild Plants and Forest Tree Species in the Nordic Countries. L. Skärby and H. Pleijel (eds), Nordic Council of Ministers, Copenhagen, TemaNord 582, 54–59.

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Brandt, J., T. Mikkelsen, S. Thykier-Nielsen and Z. Zlatev (1996). Using a combination of two models in tracer simulations. *Math. Comput. Modelling*, **23**, 99–115.

Clausen, S., A. Morgenstjerne and O. Rathmann (1996). Measurement of surface temperature and emissivity by a multitemperature method for Fourier-transform infrared spectrometers. *Applied Optics*, **35**, 5683–5691.

Dannemand Andersen, P., E.L.Petersen, P.H. Jensen, J. Beurskens, G. Elliot and J.P. Molly (1996). Wind energy. In: The Future For Renewable Energy. Prospects and directions. James & James Ltd., London, 154–183.

Dannemand Andersen, P. (1996). Wind electricity generation. Utilities for China.

Gong Wen Kang (ed), Sterling Publications Limited, London, 91–95.

Duijm, N.J., S. Ott and M. Nielsen (1996). An evaluation of validation procedures and test parameters for dense gas dispersion models. *J. Loss Prev. Ind.*, **5**, 323–338.

Dyken, R.D. van, J.A. Ekaterinaris, M.S. Chandrasekhara and M.F. Platzer (1996). Analysis of compressible light dynamic stall flow at transitional Reynolds numbers. *AIAA J.*, **34**, 1420–1427.

Ekaterinaris, J.A. and M.F. Platzer (1996). Numerical investigation of stall flutter. *J. Turbomachinery*, **118**, 197–203.

Frandsen, S. and P. Dannemand Andersen (1996). Wind farm progress in Denmark. *Renewable Energy*, **9**, 848–852.

Frank, H.P. (1996). A simple spectral model for the modification of turbulence in flow over gentle hills. *Boundary-Layer Meteorol.*, **79**, 345–373.

Geernaert, L.L.S., E. Vignati, G. de Leeuw, M. Schulz, E. Plate and J. Højstrup (1996). Influence of sea spray on HNO_3 fluxes. *J. Aerosol Sci.*, Suppl. 1, **27**, 597–598.

Gryning, S.E. and E. Batchvarova (1996). A model for the height of the internal boundary layer over an area with an irregular coastline. *Boundary-Layer Meteorology*, 25th Anniversary Volume 1970–1995, **78**, 405–413.

Jensen, N.O., C.B. Hasager, H.P. Frank, J. Mann and L. Mahrt (1996). Development of a microscale model for the averaging of surface fluxes in inhomogeneous terrain. In: Heat, Moisture and Mass Exchange Processes on a Regional Scale in a Non-Homogeneous Terrain, Final Report environment program, F. Fielder (ed), Institut für Meteorologie und Klimaforschung, Universität Karlsruhe, Germany, Chapter C, 29 pp.

Larsen, S.E. (1996). Executive summary of scientific achievements. In: Ocean Margin Exchange OMEX. Final report subproject F: Carbon Cycling and Biogases. Université Libre, Brothel's, Belgium, F,iii – F,vi.

Larsen, S.E. and L.L. Sørensen (1996). Objectives and main results obtained. In: G. de Leeuw, A.I. Flossmann, E.J. Ljungström, P.G. Mestayer, S.E. Larsen and P.J.H. Builtjes, N-Compounds in the Marine Atmosphere: Transformation, Aerosols, Entrainment and Deposition (NTRANS), 1994 progress. TNO-Report FEL–95–C310, 34–37.

Larsen, S.E. and F.Aa. Hansen, G. de Leeuw and G.J. Kunz (1996). Micrometeorological estimation of fluxes of CO_2, heat, humidity and momentum in the marine atmospheric surface layer during OMEX. In: Ocean Margin Exchange OMEX. Final report Subproject F: Carbon Cycling and Biogases. Université Libre, Brothel's, Belgium, F.1 – F.38.

Leeuw, G. de, G.J. Kunz, S.E. Larsen and F.Aa. Hansen (1996). Physical parameters controlling fluxes in the marine surface layer. In: Ocean Margin Exchange OMEX. Final Report Subproject F: Carbon Cycling and Biogases. Université Libre de Brothel's, F39–F81.

Mahrt, L., D. Vickers, J. Howell, J. Højstrup, J.M. Wilczak, J. Edson and J. Hare (1996). Sea surface drag coefficients in the Risø air-sea experiment. *J. Geophys. Res.*, **101**, 14327–14335.

Mikkelsen, Teis N., H. Ro-Poulsen, M.F. Hovmand, P. Hummelshøj and N.O. Jensen (1996). Carbon and water balance for a mixed forest stand in relation to ozone uptake. In Critical Levels for Ozone. Experiment with Crops, Wild Plants and Forest Tree Species in the Nordic Countries. Nordic Council of Ministers, L. Skärby and H. Pleijel (eds). TemaNord 1996:582, paper no 13, 80–85.

Mortensen, L. and H.E. Jørgensen (1996). Responses of spring wheat (Triticum Aestivum L.) to ozone produced by either electric discharge and dry air or by UV lamps and ambient air. *Environ. Pollut.*, **93**, 121–127.

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Nielsen, T., H.E. Jørgensen, J.C. Larsen and M. Poulsen, M. (1996). City air pollution of polycyclic aromatic hydrocarbons and other mutagens: occurrence, sources and health effects. *Sci. Total Environ.*, **189/190**, 41–49.

Nielsen, T., K. Pilegaard, A.H. Egeløv, K. Granby, P. Hummelshøj, N.O. Jensen, and H. Skov (1996). Atmospheric nitrogen compounds: occurrence, composition and deposition. *Sci. Total Environ.*, 459–465.

Pilegaard, K., N.O. Jensen and P. Hummelshøj (1995). Seasonal and diurnal variation in the deposition velocity of ozone over a spruce forest in Denmark. *Water, Air Soil Pollut.*, **85**, 2223–2228.

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Rotach, M.W., S.E. Gryning and C. Tassone (1996). A two-dimensional Lagrangian stochastic dispersion model for daytime conditions. *Q. J. R. Meteorol. Sin.*, **122**, 367–389.

Sempreviva, A.M. and S.E. Gryning (1996). Humidity fluctuations in the marine boundary layer measured at a coastal site with an infrared humidity sensor. *Boundary-Layer Meteorol*, **77**, 331–352.

Sørensen, P., J.O. Tande, L.M. Søndergaard and J.D. Kledal (1996). Flicker emission levels from wind turbines. *Wind Eng.*, **20**, 39–46.

7.2 Articles in Danish periodicals, reports and books

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Johnson, H.K., H.J. Vested, J. Højstrup and S.E. Larsen (1996). On the dependence of sea surface roughness on wind waves. In: On Wind-wave Interaction in Coastal and Shallow Waters. Danish Hydraulic Institute, Risø Air-Sea Exchange, 8074, 32 pp.

7.3 Risø reports

Astrup, P., N.O. Jensen and Torben Mikkelsen (1996). Surface roughness model for LINCOM. Risø–R–900(EN), 31 pp.

Batchvarova, E. and S.E. Gryning (1996). Meteorological measurements, wind climatology, atmospheric turbulence and internal boundary layer development in Athens during the MEDCAPHOT-Trace experiment. Risø–R–877(EN), 26 pp.

Bindner, H., P. Vionis, E.S. Lascorz, I.C. Cruz, P. Lundsager, H. Bjerregård and B. Juul Jensen (1996). APAS-project: Feasibility studies on combined wind diesel desalination in Greece and Spain. Final report. Risø–R–912(EN), 25 pp.

Dahl, K.S. (1996). Aeroacoustic computation of low Mach number flow.Ph.D. thesis. Risø–R–947(EN), 76 pp.

Dannemand Andersen, P. and B. Skrumsager (1996). Meteorology and Wind Energy Annual Progress Report 1 January – 31 December 1995. Risø–R–879(EN), 42 pp.

Dannemand Andersen, P.D. and P. Fuglsang (1996). Evaluation of the development within wind-power technology. Risø–R–829(DA), 48 pp.

Frandsen, S. (ed), L. Chacón, A. Crespo, P. Enevoldsen, R. Gómez-Elvira, J. Headland, J. Højstrup, F. Manuel, K. Thomsen and P. Sørensen (1996). Measurements on and modelling of offshore wind farms. Risø–R–903, 100 pp.

Fuglsang, P. and H. Aagaard Madsen (1996). Implementation and verification of an aeroacoustic noise prediction model for wind turbines. Risø–R–867(EN), 53 pp.

Hummelshøj, P. (ed) (1996). Proceedings of The NOSA/NORSAC Symposium 1996, Helsingør, Denmark, 15–17 November 1996, Risø–R–934(EN), 151 pp.

Johansen, J. (1996). Implementation of Johnson-King turbulence model. Risø–R–886(EN), 25 pp.

Jørgensen, P., J.S. Christensen, J.O. Tande, A. Vikkelsø and P. Nørgård (1996). Wind-turbine impact on voltage quality. Part 1: stationary voltage conditions (in Danish). Risø–R–853(Pt.1)(DA), DEFU-TR-362, 188 pp.

Larsen, G.C. (ed) (1996). Contributions from the Department of Meteorology and Wind Energy to the EUWEC'96 European Wind Energy Conference and Exhibition, Göteborg, Sweden. Risø–R–909(EN), 44 pp.

Larsen, G.C. and K. Thomsen (1996). Low cycle fatigue loads. Risø–R–913(EN), 21 pp.

Lauritzen, B., A. Damkjær, F. Nielsen, S.P. Nielsen, E. Nonbøl and S. Thykier-Nielsen (1996). Appraisal of the consequences in Danish territory of a severe nuclear accident caused by Ignalina, Lithuania. Risø–R–892(DA), 36 pp.

Nielsen, M. and S. Ott (1996). Fladis field experiments, final report. Risø–R–898(EN), 34 pp.

Sørensen, N.N. (1995). $k-\omega$ turbulence models implementation and testing. Risø–R–864(EN), 19 pp.

Sørensen, P. and J. Dyring Kledal (1996). Wind-turbine impact on voltage quality. Part 2: flicker. Risø–R–853(Pt.2)(DA), DEFU–TR–362, 62 pp.

Tande, J.O., P. Nørgaard, P. Sørensen, L. Søndergård, P. Jørgensen, A. Vikkelsø, J. Dyring Kledal and J.S. Christensen (1996). Wind-turbine impact on voltage quality. Summary report (in Danish). Risø–R–853(Summ.)(DA), DEFU–TR–362, 37 pp.

Thomsen, K., S. Markkilde Petersen, J. Thirstrup Petersen, S. Øye and M. Friedrich (1996). Terrain induced loads on pitch regulated wind turbines. Risø–R–846(EN), 81 pp.

Tveten, U. and T. Mikkelsen (eds) (1996). Report of the Nordic dispersion/trajectory model comparison with the ETEX-1 full-scale experiment. NKS/EKO-4 intercomparison/validation exercise held at Risø National Laboratory, NKS-EKO-4(95)1 (1995), Risø–R–847(EN), 98 pp.

Vikkelsø, A., L. Søndergård, P. Nørgaard and P. Jørgensen (1996). Wind-turbine impact on voltage quality. Part 3: harmonics and operational conditions during use of rectifier. Risø–R–853(Pt.3)(DA), DEFU–TR–362, 95 pp.

7.4 Internal Risø reports

Aagaard Madsen, H., P. Fuglsang, S. Øye, C.H. Westergaard, M. Friedrich and L. Jensen (1996). Blade design EFP 95. Preproject – aerodynamics. Risø–I–931(DA), 72 pp.

Antoniou, I., H. Aagaard Madsen and F. Rasmussen (1996). Wind tunnel measurements on a LM 8.2 m blade. Risø–I–800(EN), 88 pp.

Antoniou, I. and S. Markkilde Petersen, S. (1995). Wind turbine test: structural loads ELKRAFT 1MW. (Stall regulated operation). Risø–I–865(EN), 219 pp.

Antoniou, I. and S. Markkilde Petersen (1996). Wind turbine test: structural loads (new yaw condition). ELKRAFT 1MV (stall regulated operation). Risø–I–866(EN), 46 pp.

Bindner, H., E.S. Lascorz, E.S. and P. Vionis (1996). APAS-project: feasibility studies on combined wind diesel desalination in Greece and Spain. Second interim report 01.07.1995 - 31.12.1995. Risø–I–987(EN), 73 pp.

Bindner, H., P. Vionis, P. Lundsager, H. Bjerregård and B. Juul Jensen (1996). Wind diesel desalination systems on Paros. Feasibility report. APAS-project: feasibility studies on combined wind diesel desalination in Greece and Spain. Risø–I–1042(EN), 127 pp.

Bindner, H. and P. Lundsager, P. (1996). Danvest power unit for wind diesel power stations. Function and performance tests of unit installed with desalination plant. Risø–I–988(EN), vp.

Bindner, H., E.S. Lascorz, I.C. Cruz, P. Lundsager, H. Bjerregård and B. Juul Jensen (1996). Wind diesel desalination systems on Menorca. Feasibility report. Risø–I–1043(EN), 94 pp.

Electricity from renewables (1996). Part 1: General report. Part 2: Technical report. Risø–I–1039(EN), 186 pp.

Fabian, O. (1993). Type testing. Load measurements Micon M750/400. Risø–I–736(EN), 265 pp.

Fabian, O. (1993). Type testing. Functional testing Micon M750/400. Risø–I–737(EN), 90 pp.

Filippone, A. and H. Aagaard Madsen (1995). Notes on airfoil design. Risø–I–896(EN), 58 pp.

Hansen, J.C., J.O. Tande, N. Juhl Thomsen, P Skjerk Christensen, P. Nørgård and P. Lund (1996). Cape Verde wind farms. Step 2. Feasibility report. Veal. 1: Crosscutting analysis and draft project document. Risø–I–1065(EN), 44 pp.

Hansen, J.C., J.O. Tande, J.O., N. Juhl Thomsen, P. Skjerk Christensen, P. Nørgård and P. Lund (1996). Cape Verde wind farms. Step 2. Feasibility report. Veal. 2: Technical and economic power system analysis. Risø–I–1066(EN), vp.

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Krabbe, U. (1996). Wind turbine generators. Direct coupling to the rotor shaft. Risø–I–956(DA), 34 pp.

Mortensen, N.G., L. Landberg, I. Troen and E.L. Petersen (1996). Wind Atlas Analysis and Application Program (WAsP) Vol.3: Utility Programs. Risø–I–666(v.3)(ed.2)(EN), 42 pp.

Mortensen, N.G. (1996). Tétouan wind farm, Morocco. Estimated wind resources and wind turbine power production. Prepared for Consortium EDF-Germa, Paris, France. Risø–I–1045(EN), 41 pp.

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Nørgård, P.(ed) (1996). Report on meeting "Summing-up and finish" CTH, Göteborg, May 1996. Nordic group on co-operation: electric-technical possibilities of wind turbines. Risø–I–1033(DA), 52 pp.

Schmidt Paulsen, U. (1996). Conceptual test of Nordtank NTK 500/41. Structural loads. Risø–I–936(DA), 115 pp.

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Helm (eds), H.S. Stephens & Associates, Bedford, 979–981.

Sørensen, N.N. (1996). Static stall predictions. In: IEA Joint Action. Aerodynamics of Wind Turbines. Proceedings of Ninth Symposium on Aerodynamics of Wind Turbines, Stockholm, Sweden, 11-12 December 1995. B. Maribo Pedersen (ed), Technical University of Denmark, Department of Fluid Mechanics, 27–49.

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Thirstrup Petersen, J. (1996). The aeroelastic code HawC – model and comparisons. In: State of the Art of Aeroelastic Codes for Wind Turbine Calculations. Proceedings of 28th Meeting of Experts, Lyngby, Denmark, 11–12 April 1996. B. Maribo Pedersen (ed), Technical University of Denmark, Department of Fluid Mechanics, 129–135.

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Westermann, D., H. Klug, I. Ravey, R. Hunter, E. Morfiadakis, O. Fabian, T. Friis Pedersen, S. Petersen and N. van der Borg (1996). Wind speed measurements and anemometer calibration. Proceedings of the EUWEC'96 European Wind Energy Conference and Exhibition, Göteborg, Sweden, 20–24 May 1996. A. Zervos, H. Ehmann and P. Helm (eds), H.S. Stephens & Associates, Bedford, 1008–1011.

7.10 Lectures at international conferences and meetings

Barthelmie, R.J., J. Højstrup and M.S. Courtney (1996). Coastal and offshore wind power production – modelling and observations. Conference on Coastal and Atmospheric Prediction, Atlanta, Georgia, USA, 28 January - 2 February 1996. AMS, Boston, USA.

Barthelmie, R.J., B. Grisogono and S.C. Pryor (1996). Diurnal variability of wind

speeds over land and sea - observations and simulations. Conference on Coastal and Atmospheric Prediction, Atlanta, Georgia, USA, 28 January - 2 February 1996. AMS, Boston, USA.

Beurskens, J., P. Dannemand Andersen, E.L. Petersen and A. Garrad (1996). Wind energy. EuroSun'96 10th International Conference, Freiburg, Germany, September.

Dannemand Andersen, P. (1996). Wind turbine technology. Future trends and requirements. FAG Schweinfurt, Schweinfurt, Germany, 24 September.

Dannemand Andersen, P. (1996). Short overview of Risø wind energy activities. Workshop on WT certification. Center for Renewable Energy Sources, Pikermi, Greece, 7–8 October.

Dannemand Andersen, P. (1996). The philosophy behind the Danish certification system for WTs and a historical overview. Workshop on WT certification. Centre for Renewable Energy Sources, Pikermi, Greece, 7–8 October.

Dannemand Andersen, P. (1996). The certification system today. Workshop on WT certification. Centre for Renewable Energy Sources, Pikermi, Greece, 7–8 October.

Dannemand Andersen, P. (1996). International standardization. Workshop on WT certification. Centre for Renewable Energy Sources, Pikermi Greece, 7–8 October.

Dannemand Andersen, P., P. Hjuler Jensen and B. Juel Jensen (1996). Electricity from renewables. ALTENER project AL/71/93/DK. The ALTENER program: renewable energy entering the 21st century, Barcelona, Spain, 25–27 November 1996.

Donaldson, A.I., R. Lattuada, D.K.J. Mackay, R.P. Kitching, J.H. Sørensen, O.C. Jensen and T. Mikkelsen (1996). Analysis and prediction of the airborne spread of food-and-mouth disease virus using AIRPLOT, a GIS-based atmospheric dispersion system. Fourteenth IPVS Congress, Bologna, Italy, 7–10 July, 1996.

Ekaterinaris, J.A. (1996). Computation of unsteady separated flows with one- and two-equation turbulence models. Technical University of Hamburg, Germany, July.

Ekaterinaris, J.A. (1996). Numerical investigation of dynamic stall. Technical University of Stuttgart, Germany, July.

Ekaterinaris, J.A. (1996). Numerical investigation of wind turbine aerodynamics and aeroacoustics. NASA-Ames Research Center, Moffett Field, CA, USA, December.

Ekaterinaris, J.A. (1996). Numerical solution of the linearized euler equations with a high-order compact scheme. Second Aeroacoustics Workshop, Tallahassee, FL, USA, November.

Ekaterinaris, J.A. and D.H. Kristian (1996). Numerical prediction of the sound filed of a cylinder generated by low speed turbulent flow. Second Aeroacoustics Workshop, Tallahassee, FL, USA, November.

Hansen, J.C., U.S. Paulsen, A. El Hewehy and E. Sayed Monsour (1996). The wind energy technology centre in Hurghada. Background, facilities and perspectives. NREA-Danida Wind Energy Workshop, Hurghada, Egypt, 14–16 Jan 1996.

Hasager, C.B. (1996). The relationship between landscape structure at different spatial scales. Workshop on Remote Sensing of Landscape Structure and its Use in Environmental Monitoring. Roskilde University Centre, Denmark 20–21 March.

Hasager, C.B. (1996). Upscaling the aerodynamic roughness from satellite data. In: Notes from Internal DANMAC Seminar 3/96, Geographic Institute, University of Copenhagen.

Hasager, C.B. and N.O. Jensen (1996). Satellite-based surface flux retrieval in heterogeneous landscape. Programme and Summary. Danish Remote Sensing

Society Annual Meeting, Technical University of Denmark, Lyngby, December.
Hummelshøj, P. (1996). Deposition of aerosols, physical processes. Workshop on Atmospheric Deposition and Surface Exchange, NERI (National Environmental Research Institute) and Risø National Laboratory, 11–12 April 1996.
Hummelshøj, P. (1996). Micrometeorological measuring methods, eddy correlation and gradient methods. Workshop on Atmospheric Deposition and Surface Exchange, NERI (National Environmental Research Institute) and Risø National Laboratory, 11–12 April 1996.
Højstrup, J. (1996). The RASEX experiments. Geographical Department, Swiss Federal Institute of Technology (ETH), Switzerland, 2 April.
Højstrup, J. (1996). RASEX. Waves and sea surface roughness. MIUU, Uppsala, Sweden, 7 June.
Højstrup, J. and K.S. Hansen (1996). Data base on wind characteristics. AWEA Conference, Denver, CO, USA, July 1996.
Højstrup, J. (1996). Spectral coherence in wind-turbine wakes. Proceedings of the AWEA Conference, Denver, CO, USA, July 1996.
Højstrup, J. (1996). The dependence of sea surface roughness on waves. Marine Boundary Layer Accelerated Research Initiative, Experiment Review. Scripps Institution of Oceanography, San Diego, CA, USA, 28 October.
Højstrup, J. (1996). The dependence of sea surface roughness on waves. MMM/ATD, National Center for Atmospheric Research, Boulder, CO, USA, 1 November.
Højstrup, J. (1996). Sea surface roughness derived from wave spectra. Atmospheric Sciences, Oregon State University, Corvallis, OR, USA, 21 November.
Jensen, N.O. (1996). Ground level concentrations resulting from continuous releases under a range of exposure time conditions. Ninth Joint Conference on Applications of Air Pollution Meteorology with A&WMAS, Atlanta, Georgia, USA, 28 January – 2 February 1996.
Jensen, N.O. (1996). Various aspects of the atmospheric boundary layer structure with relevance to pollution dispersion. Proceedings of Ninth Joint Conference on Applications of Air Pollution Meteorology with A&WMAS, 28 January – 2 February 1996.
Jensen, N.O. (1996). Landscape structure and microclimatic atmospheric input to specific landscape elements. Roskilde University Centre, 22 March.
Jensen, N.O. (1996). Euroflux and TRACT. Workshop on Atmospheric Deposition and Surface Exchange, NERI (National Environmental Research Institute) and Risø National Laboratory, 11–12 April 1996.
Jensen, N.O. (1996). Deposition of gases, physical processes. Workshop on Atmospheric Deposition and Surface Exchange, NERI (National Environmental Research Institute) and Risø National Laboratory, 11–12 April 1996.
Jensen, N.O. (1996). Aggregation of surface fluxes in non-homogeneous terrain. Symposium on Water Flux Regulation in Forest Stands, Castle Thurnau, Germany, 14–18 September.
Jensen, N.O. (1996). Aggregation of surface fluxes in non-homogeneous terrain. Symposium on Water Flux Regulation in Forest Stands. BAHC Meeting, University of Bayreuth, Germany, 22–23 October.
Jensen, N.O. (1996). Aggregation of surface fluxes in non-homogeneous terrain. Institut für Meteorologie, Leipzig, Germany, 24 October.
Jørgensen, H.E. and T. Mikkelsen (1996). Diffusion analysis of ground-released smoke plumes. Ninth Joint Conference on Applications of Air Pollution Meteorology with A&WMAS, Atlanta, Georgia, USA, 28 January – 2 February 1996.
Larsen, S.E. (1995). Since the Risø Workshop. MAGE-EUROTRAC Workshop on Marine Gas and Aerosol Exchange, Mainz, Germany, 1–5 November.

Larsen, S.E. (1996). The role of air-sea exchange in marine programs. Second EC-MAST MTP Conference, Iraclion, Greece, 1–3 February.

Larsen, S.E. (1996). International air-sea exchange programs. Workshop on Atmospheric Deposition and Surface Exchange, NERI (National Environmental Research Institute) and Risø, 11–12 April 1996.

Larsen, S.E. (1996). The research of Sergej Zilitinkevich and its influence on boundary-layer meteorology after 1990. Presented at Symposium in honour of Sergej Zilitinkevich, Bremerhaven, Germany, 3 May.

Leeuw, G. de, G.J. Kunz, S.E. Larsen and F.Aa. Hansen (1996). Over-water CO_2 flux measurements. International Congress on Environment/Climate ICEC-96, Rome, Italy, 4–8 March 1996.

Leeuw, G. de, G. Gaulliez, D. Woolf, P. Bowyer, P. Nightingale, S. Rapsomanikis, S.E. Larsen and D. Spiel (1996). Effects of breaking waves on air-sea exchange gas transfer. Pacific Ocean Remote Sensing Conference on Ocean Science and Probing. Symposium on the Role of Satellite Remote Sensing in Assessing Global Air-Sea Gas Transfer, Victoria, B.C., Canada, 13–16 August 1996.

Lenschow, D.H., Qing Wang, S.P. Oncley, K.J. Davis and J. Mann (1996). Lake-induced modification of the boundary layer over the Boreal Forest. Contribution to 22nd Conference on Agricultural and Forest Meteorology, 76th Annual Meeting of the American Meteorological Society, January 1996, Atlanta, Georgia, USA.

Mortensen, N.G. and Usama Said Said (1996). Wind Atlas for the Gulf of Suez. Measurements and modelling 1991–1995. Invited presentation at at the NREA-Danida Wind Energy Workshop, Hurghada, Egypt, 15 January.

Oncley, S.P., D.H. Lenschow, K.J. Davis, T.L. Campos, and J. Mann (1996). Regional-scale surface flux observations across the Boreal forest during BOREAS. Contribution to 22nd Conference on Agricultural and Forest Meteorology, 76th Annual Meeting of the American Meteorological Society, January 1996, Atlanta, Georgia, USA.

Petersen, E.L. Status of wind power exploitation world-wide NREA-Danida Wind Energy Workshop, Hurghada, Egypt, 14–16 January 1996.

Petersen, E.L. (1996). Wind energy conversion. Fifth International Summer School Solar Energy '96. Technologies, Applications, Economics. University of Klagenfurt, Austria, 29 July – 9 August.

Petersen, E.L. (1996). Wind energy meteorology. Eurosun '96 Conference, Freiburg, Germany, September.

Petersen, E.L. (1996). Wind energy in Europe. Conference and Exhibition on Development of the Wind Power Industry: the European Strategy. Rimouski Congress Centre, University of Quebec, Canada, 25–26 October.

Pryor, S.C., R.J. Barthelmie and O. Hertel (1996). Modeling aerosol concentrations and speciation in the lower Fraser Valley, British Columbia. Conference on Urban and Biometeorology, Atlanta, Georgia, USA, 28 Jan – 2 Feb 1996.

Pryor, S.C. and R.J. Barthelmie (1996). Aerosol formation: observation and parametrization. Environmental Protection Agency, Research Triangle Park, April.

Pryor, S.C. and R.J. Barthelmie (1996). Emission scenarios - aerosol responses. Meeting on Aerosol and Cloud Parametrization, St. Louis, USA, May 1996.

Pryor, S.C., R.J. Barthelmie, T. King, S. Bohme, R. McLaren and N. Suzuki (1996). Quantifying the impact of precursor variability on ozone concentrations. Invited speaker, 89th Annual Conference of the Air and Waste Management Association, June.

Pryor, S.C. and R.J. Barthelmie (1996). Application and evaluation of ACDEP in the LFV: emission scenarios and meteorological/chemical parametrizations. Meeting on Environment Canada's Acidification Program, Toronto, Canada, October 1996.

Pryor, S.C. and R.J. Barthelmie (1996). Application of an aerosol model to the Lower Fraser Valley. Pacific Northwest International Section of A&WMA, Seattle, WA, USA, December.

Pryor, S.C. and R.J. Barthelmie (1996). Analysis of REVEAL and REVEAL II data sets to determine causes, frequency and severity of visibility episodes. Pacific Northwest International Section of A&WMA, Seattle, WA, USA, December.

Schulz, M., G. de Leeuw, S.E. Larsen and T. Stahlschmidt (1996). Vertical profiles of marine aerosols measured at the research platform "Nordsee". Proceedings of European Aerosol Conference, Delft, The Netherlands, 9–11 September 1996.

Søndergaard, L.M. (1996). Testing of a direct drive generator for wind turbines. AWEA '96 Conference, American Wind Energy Association, Denver, CO, USA, 24–27 June.

Sørensen Geernaert, L.L. (1996). Marine ecosystems. Workshop on Atmospheric Deposition and Surface Exchange NERI (National Environmental Research Institute) and Risø National Laboratory, 11–12 April 1996.

Sørensen, N.N. (1996). Computational and experimental studies of separated flows past 3-D wind turbine rotors. ERCOFTAC Nordic Pilot Center Meeting, Stockholm, Sweden, 5-6 September.

Tande, J.O. and J.C. Hansen (1996). Opportunities for high wind energy penetration. Energex '96. Conference on Energy Strategies in Developing Countries in the 21st Century: Challenges and Opportunities, Beijing, People's Republic of China, 3–7 June.

Winther Jensen, M. (1996). Practical experiences with the Danish certification system. Workshop on WT certification, Center for Renewable Energy Sources, Pikermi, Greece, 7–8 October.

Winther Jensen, M. (1996). Technical demands in the Danish certification system. Workshop on WT Certification. Centre for Renewable Energy Sources, Pikermi, Greece, 7–8 October.

Winther Jensen, M. (1996). Demands and procedures for authorizations. Workshop on WT Certification, Centre for Renewable Energy Sources, Pikermi, Greece, 7–8 October.

7.11 Lectures at Danish conferences and meetings

Brandt, J., T. Mikkelsen, S. Thykier-Nielsen and Z. Zlatev (1996). Diffusion – long range transport (in Danish). Centre for Air Pollution Processes and Models, Environmental Research Programme, centre meeting, Copenhagen, 29 November 1996.

Dahl, K. (1996). Numerical aeroacoustics (in Danish). Meeting concerning research projects on wind turbine technology, Risø National Laboratory, 30 May.

Frandsen, S. and J. Højstrup (1996). Perspectives for off-shore wind turbines (in Danish). Wind Day on wind energy activities at Risø in an international context. Risø National Laboratory, 14 August.

Friis Petersen, T. (1996). The wind turbine power curve - an important uncertain factor in production calculations. The latest measurement development (in Danish). Seminar on Calculations and Follow-up on Production. Energi- of Miljødata, Aalborg, Denmark 26 March.

Fuglsang, P. (1996). Wind tunnel measurements of profile effects (in Danish). Meeting concerning research projects on wind turbine technology, Risø National Laboratory, 30 May.

Fuglsang, P. (1996). Investigations of different tip shapes and applied aeroacoustics

– calculations and measurements of eg aerodynamic noise. Meeting concerning research projects on wind turbine technology Risø National Laboratory, 30 May.

Geernaert, L.L. (1996). Ammonia from the sea (in Danish). Environmental Research Programme, Annual Meeting, Centre for Air Pollution Processes and Models, Copenhagen, 29 November.

Granby, K., H. Skov, O. Hertel, C.S. Christensen, A.H. Egeløv, C. Lohse, T. Nielsen, S.E. Gryning, P. Hummelshøj and J. Platz (1996). Oxidants (in Danish). Centre for Air Pollution Processes and Models, Environmental Research Programme, centre meeting, Copenhagen, 29 November 1996.

Hansen, J.C. (1996). International co-operation among institutions – Egypt and Cape Verde (in Danish). Wind Day on wind energy activities at Risø in an international context. Risø National Laboratory, 14 August.

Harvøe, P. (1996). Electricity production using wind power (in Danish). Copenhagen, Green Cultural City 1996, Conference on Energy and Environment, Copenhagen, 20–21 May.

Hasager, C.B. (1996). Modelling with the PSUBAMS model. Ph.D Seminar on Soil-Vegetation Atmospheric Transfer (SVAT), Geographic Institute, University of Copenhagen, February.

Hasager, C.B. and N.O. Jensen (1996). Boundary layers and mesoscale models (in Danish) Environmental Research Programme, Annual Meeting, Centre for Air Pollution, Processes and Models, Copenhagen, 29 November.

Hasager, C.B. (1996) Surface fluxes in heterogeneous landscape. An application of satellite images. Phd lecture, University of Copenhagen, 13 December.

Hauge Madsen, P. (1996). International standardization and Danish wind turbines (in Danish). Wind Day on wind energy activities at Risø in an international context. Risø National Laboratory, 14 August.

Hauge Madsen, P. (1996). Wind Power (in Danish). Energy Technologies 2010 – 2020, IDA, Copenhagen, 26 September.

Jørgensen, H.E. (1996). Dispersion to the local environment (in Danish). Environmental Research Programme, Annual Meeting, Centre for Air Pollution Processes and Models, Copenhagen, 29 November.

Larsen, S.E. (1996). The Department of Meteorology and Wind Energy. The Annual Meeting of Danish Meteorological Society (DAMS), Risø National Laboratory, 16 March 1996.

Larsen, S.E. (1996). Diffusion and dispersion studies at the Department of Meteorology and Wind Energy. Visit by a Chinese meteorologist delegation at Risø National Laboratory, 25 September 1996.

Larsen, S.E. (1996). Atmospheric work at Risø National Laboratory. Visit from DANTEC A/S and China Institute of Radiation Protection, Risø National Laboratory, 23 October.

Petersen, E.L. (1996). European Wind Atlas (in Danish). Wind Day on wind energy activities at Risø in an international context, Risø National Laboratory, 14 August.

Rasmussen, F. (1996). Flexible rotor, status, plans and perspectives (in Danish). Meeting concerning research projects on wind turbine technology, Risø National Laboratory, 30 May.

Rasmussen, F., J. Nørkær Sørensen and P. Hauge Madsen (1996). Aeroelastic research, status and perspectives (in Danish). Meeting concerning research projects on wind turbine technology, Risø National Laboratory, 30 May.

Søndergård, L. (1996). Inverter technology for wind turbines (in Danish). Meeting on grid connection of wind turbines, Risø National Laboratory, 13 March.

Søndergård, L. (1996). Investigations of multipolar generators for wind turbines (in Danish). Meeting on multipolar generators for wind turbines, Risø National

Laboratory, 31 October.

Sørensen, N. and M. Hansen (1996). Aerodynamic 3D simulations (eg LM 19.1 blade) (in Danish). Meeting concerning research projects on wind turbine technology, Risø National Laboratory, 30 May.

Sørensen, P. (1996). Flicker from wind turbines (in Danish). Meeting on grid connection of wind turbines, Risø National Laboratory, 13 March.

Tande, J.O. (1996). Probabilistic load-flow analyses and voltage dependent disconnection of wind turbines (in Danish). Meeting on grid connection of wind turbines, Risø National Laboratory, 13 March.

Tande, J.O. (1996). Electronic power-compensation unit – a JOULE project (in Danish). Meeting on grid connection of wind turbines, Risø National Laboratory, 13 March.

Thirstrup Petersen, J. (1996). Edgewise vibrations and dynamic stall – inflow measurements (in Danish). Meeting concerning research projects on wind turbine technology, Risø National Laboratory, 30 May.

Thomsen, K. (1996). Design load basis - results from Sky River and Vindeby (in Danish). Meeting concerning research projects on wind turbine technology, Risø National Laboratory, 30 May.

Thomsen, K. (1996). Blade design, status and plans for the project (in Danish). Meeting concerning research projects on wind turbine technology, Risø National Laboratory, 30 May.

Thomsen, K. and S. Markkilde Petersen (1996). Design of wind turbines for complex terrain (in Danish). Wind Day on wind energy activities at Risø in an international context, Risø National Laboratory, 14 August.

Winther-Jensen, M. (1996), Status after five years of wind turbine approval (in Danish). Wind Day on wind energy activities in an international context, Risø National Laboratory, 14 August.

Winther-Jensen, M., (1996). Demands on overloading abilities for wind turbine generators (in Danish). Meeting on multipolar generators for wind turbines, Risø National Laboratory, 31 October.

7.12 Educational activities

Barthelmie, R.J. (1996). Meso- to microscale. "Introduction to Micrometeorolgy", course, University of Lund, Sweden, lecture, April.

Barthelmie, R.J. (1996). Evolution of planetary atmospheres. "Environmental Change", course, Indiana University, Bloomington, Indiana, USA, lecture, October.

Landberg, L. and N.G. Mortensen (1996). Three-day course in WASP: the Wind Atlas Analysis and Application Program. Training Workshop on Wind Flow Modelling. National Aerospace Laboratories, Bangalore, India, 14–17 November.

Mortensen, N.G. (1996). One-day course in WASP: the Wind Atlas Analysis and Application Program. Risø National Laboratory, Roskilde, Denmark, 29 May.

Mortensen, N.G. and L. Landberg (1996). One-day course in WASP: the Wind Atlas Analysis and Application Program. Nordtank Energy Group, Balle, Denmark, 4 December.

Seminars held in the department

Barthelmie, R.J. "Diurnal cycles of wind speeds in coastal areas", May.

Bergmann, Juan "Some methodical and physical problems of the PBL concepts and a new concept that avoids them", March.

Beyrich, Frank "Estimation of the entrainment zone depth in a shallow convective boundary layer from sodar data", September.

Bowen, Anthony "Exploring the limits of WASP, the wind atlas analysis and application program", May.

Cherry, N. "Wind energy resource survey of New Zealand: its history and current implementation", August.

Cohr, Karl-Heinz "Principles of toxiology with emphasis on human responses to toxicants", February.

Deichmann, Flemming "The Test Station within a fixed framework – a new wind energy centre at Risø National Laboratory?", August.

Ekaterinaris, John "An upwind scheme for the computation of acoustic fields generated by incompressible flow", October.

Fisichella, Chris "Aerodynamic calculation programs", lecture for the AWEA conference, June.

Hardin, Jay "Approaches to computational aeroacoustics", November.

Heathfield, Duncan "Using WASP to predict storm damage to forests", June.

Kacholdt, Oliver "Wind-battery system control strategies", September.

Kamada, Ray "SF_6 plume/puff release study: z = 0 - 1200 m from the Cape Canaveral Model Validation Program: 1995-96", May.

Langreder, W. "Models for variable speed wind turbines", September.

Lenschow, Don ''New perspectives on marine stratiform clouds", March

Pécseli, Hans "Recent investigations of Eulerian-Lagrangian velocity correlations and concentration fluctuations in 2-D turbulence", January.

Pryor, Sara "Observations and simulations of fine aerosol concentration and speciation", August.

Riba, Josep "Exploitation of low speed winds: aerogenerator superconductor I", August.

Santabárbara, Josep Moreno "Thermal forcing of Lincom", October.

Selvam, R. Panneer "Computer modelling of flow and pollutant transport around a building", July.

Tsinober, Arkady "How much is turbulence non-gaussian? On some non-gaussian aspects of turbulence", October.

Zilitinkevich, Sergei "Further discussion on heat and mass transfer in shear free convection", June.

Bibliographic Data Sheet **Risø–R–948(EN)**

Title and author(s)

Meteorology and Wind Energy Department
Annual Progress Report 1996

P. Hauge Madsen, P. Dannemand Andersen and B. Skrumsager (eds)

ISBN	ISSN
87–550–2251–0	0106–2840 0903–9627

Dept. or group	Date
Meteorology and Wind Energy	July 1997

Groups own reg. number(s)	Project/contract No.

Pages	Tables	Illustrations	References
67	4	5	0

Abstract (Max. 2000 char.)

In 1996 the Meteorology and Wind Energy Department has performed research within the programme areas: (1) wind energy and (2) atmospheric processes. The objectives are through research in boundary layer meteorology, fluid dynamics, aerodynamics and structural mechanics to contribute with new knowledge within (1) wind energy in relation to development, manufacturing, operation and export as well as testing and certification of wind turbines, and (2) aspects of boundary-layer meteorology related to environmental and energy problems of society. The work is supported by the research programs of the Ministry of Environment and Energy, the Nordic Council of Ministers, EU as well as by industry.

Through our research and development work we develop and provide methodologies including computer models for use by industry, institutions, and governmental authorities. In the long view we are developing facilities and programs enabling us to serve as a national and European centre for wind-energy and boundary-layer meteorological research.

A summary of our activities in 1996 is presented.

Descriptors INIS/EDB

AIR POLLUTION MONITORING; BOUNDARY LAYERS; METEOROLOGY; PROGRESS REPORT; RESEARCH PROGRAMMES; RISOE NATIONAL LABORATORY; TURBULENCE; WIND POWER; WIND TURBINES

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Information Service Department, Risø National Laboratory
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E-mail: infserv@risoe.dk · Telex 43 116